EFFECT OF ROAD GEOMETRIC DESIGN ELEMENTS ON ROAD TRAFFIC CRASH FREQUENCY

CASE STUDY: BOLE SUB-CITY, ADDIS ABABA

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MASTER OF SCIENCE

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

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By

ALEMAYEHU FEYISSA GERBA

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DECLARATION

I hereby declare that this thesis entitled "**Effect of Road Geometric Design Elements on Road Traffic Crash Frequency"** was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or processional qualification.

Alemayehu Feyissa Gerba		
Author	Signature	Date

CERTIFICATE

This is to certify that the thesis prepared by **Mr. Alemayehu Feyissa Gerba** entitled "**Effect of Road Geometric Design Elements on Road Traffic Crash Frequency"**, submitted in fulfillment of the requirements for the Degree of Master of Science complies with the regulations of the university, and meets the accepted standards with respect to originality and quality.

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DEDICATION

To my late mother Marema Gonfa. Mother, I will always remember your fantasy to my future brightness and I am growing to become what you were dreaming.

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ABSTRACT

Road crashes have been increasing in alarming rate and it is a serious problem all over the world. In Ethiopia, Addis Ababa City has taken the leading road traffic crashes, particularly in Bole Sub-city. Any causes of road crashes fall under road users, road characteristics and vehicles factors. Road characteristics had been chosen for investigation and explanations were given to the extent in which they affect road safety.

The objective of this research was to investigate the effect of road geometric design elements on road traffic crash occurrences at road segments in Bole Sub-city. To conduct this study, data were collected on geometric characteristics, the number of crashes and traffic volume from the twenty-two road segments. Mid-blocks were selected based on the convenience sampling method. A total of 5,825 road crashes were collected from the Bole Sub-city Police Station and Addis Ababa Police Commission over a period of three years, between July 2015 and June 2018. Poisson regression model and a Negative binomial regression model were applied to develop a crash prediction model. In addition to this, descriptive statistics was used to conclude the nature and characteristics of crash occurrences in the Bole Sub-city. A sum of 15,548 road crashes were gathered for consecutive of three years that comprises; 219 fatal, 1,470 injuries and 13,859 property damage only for the general analysis in the Sub-city.

The result of this study shows, there is a strong correlation between road geometric design elements and road crash occurrence. The modeling result indicated that median type, number of horizontal curves, number of vertical curves, number of lanes, sidewalk width, number of access, number of access controls and average daily traffic are significantly affecting road crash occurrences. The general analysis in the Sub-city reveals that most crashes occurred at road segments, undivided two-way and one-way roads, particularly in market and recreation areas. The result of this study supports the transport planner and road designer in consideration of road safety issue, and sustainable road design standards.

Keywords: Negative binomial regression model, Poisson regression model, Road segment, Road geometric characteristics, Road crash occurrence.

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LIST OF ABBREVIATIONS

AACTB	Addis Ababa City Road and Transport Bureau
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
AAPC	Addis Ababa Police Commission
BTPO	Bole Sub-city Traffic Police Office
CBD	Central Business District
DC	District of Columbia
ECE	Economic Commission for Europe
ERA	Ethiopian Road Authority
FPCE	Federal Police Commission of Ethiopia
GLM	Generalized linear model
GPR	Generalized Poisson regression
L	Length of road segments
MH	Median height
MT	Median type
MW	Median width
NHC	Number of Horizontal Curves
NVC	Number of Vertical Curves
NBR	Negative binomial regression
NL	Number of lanes
PDO	Property damage only
PHV	Peak hour volume
RM	Raised median
RTA	Road traffic accident
SEPAAC	Socio-Economic Profile of Addis Ababa City
St.	Street
SW	Surface width
TRANSIP	Transportation System Improvement Project
TWLTL	Two way left turn lanes
VC	Vertical Curve
WHO	World Health Organization
4WD	Four Wheel Drive

CHAPTER ONE

INTRODUCTION

1.1 Background

Addis Ababa, the largest city in Ethiopia, faces the challenges of providing reliable, efficient and safe transportation system. Even though the city currently manifests low motorization rates by global standards, with a total vehicle fleet estimated at about 60% of the total fleet of the country in 2015, the rapid economic growth currently being experienced is likely to lead to a growth in private vehicle ownership aggravating the challenges. The transport system in the city is characterized by frequent congestion and delays, a high rate of road traffic accidents and air pollution (AACTB, 2016)

Road safety is one among the serious problems in the world. According to the WHO (2015) Report, an approximated 1.25 million people are killed and up to 50 million injured worldwide every year, on average 3,287 fatalities a day in road crashes. Additionally, road traffic crashes are the leading cause of death for adolescents aged 15 to 29, cost governments approximately 3 to 5% of GDP, and about 90% of the world's fatalities on the roads occur in low and middle-income countries, which have only 54% of the world’s registered vehicles.

Road traffic crashes are the major economic, social and health problems, especially in developing countries. For example, in Ethiopia, it’s found with one of the world's worst accident records when estimated by fatality rate of 25.3 per 100,000 population, as well as road traffic crashes cost about 0.8 to 0.9 % of its gross domestic product (WHO, 2015).

Addis Ababa City has shared the highest road traffic crashes in the country. The road crash data report from the Addis Ababa Police Commission shows that between the year 2010 and 2014, about 14,263 people faced different levels of injury, while PDO as a result of the crashes was estimated to be over 19 million US dollars.

The study conducted in Bole Sub-city indicated that the Sub-city has taken the highest traffic crash frequency compared to other Sub-cities. The researcher investigated three years' total crash occurrences in the Sub-city and the estimated crashes were 2,862 in 2012/13, 3,229 in 2013/14, and 3,679 in 2014/15 year including property damage only (Alemu, 2016). These were annual increase of 12.8% between 2012/13 and 2013/14, and about 14.0% between 2013/14 and 2014/15.

Factors that cause road traffic crashes are categorized into road user factors, road characteristics factors, and vehicle factors. Hence, road factors are the scope of civil engineering professionals and considered as part of this study. It is very important for the highway to establish a harmony between all the three factors at the design stage of the highway. With standard road geometric design elements, it is possible to compensate for the other factors and thus decrease the number of road traffic crashes. Negative road engineering factors include where a road defect directly triggers a crash, where some element of the road environment misleads a road user and thereby creates an error (Dinesh et al., 2006).

The trend of crash occurrences increased in Bole Sub-city from time to time that costs human life and economy of the country. Hence, the research identified major geometric characteristics that influence road traffic crashes in this Sub-city and finally, recommendations are forwarded to facilitate road safety.

1.2 Statement of Problem

In Africa, road safety problem is more complicated, and it's known for having the highest number of road crashes compared to other regions. Most countries in this region have insufficient policies and strategies to protect vulnerable road users. Moreover, enforcemnet on major risk factors such as speed control, drunk driving, child restraints, seat belt and helmet use is not yet common in the majority of the countries of this region. Also, there is rarely traffic law enforcement, traffic regulation and post crash treatment in most countries in the region(WHO, 2013a). Hence, the complexity of road saftey in the region requires consolidated efforts to strengthen road saftey.

In Ethiopia, road traffic crash is a cause of significant losses of human life and economic resources. According to the Addis Ababa Police Commission report on road traffic crashes in the city, the trend of crashes is not in a state of declining rather has continued to rise at an alarming rate over consecutive of five years from 2010/11 to 2014/15. The reported total crashes during these years were, 13,598 without property damages only (AAPC, 2015). The Bole Sub-city Police Officers indicated that the Sub-city has recorded the worst traffic crashes compared to the vehicle density. In addition, related to other Sub-cities Bole had the highest number of road crashes.

Road segment had a considerable share of fatal and non-fatal crashes. The study conducted in the Addis Ababa depicts that about 73% of crashes happened at mid-block locations without junctions. At these sections of roads, vehicle speed is expected to be high and victims of these kinds of crashes are expected to be pedestrians (Jiregna, 2016). Also, The highest percentage of road crashes severity such as fatal injury, serious injury, minor injury and PDO occurred on straight roads, while downward sloping roads shared lower crash frequency (Tariku et al., 2017).

Some of the primary road geometric design elements that can influence road crashes on highways are horizontal curvature, vertical curve, carriageway, grade, shoulder, and median (Mohammed, 2013). Also, different investigations are classified relationship between road geometric characteristics and traffic crashes into road cross-sectional element effects and alignment effects.

According to studies made in different countries, it is possible to change the problem of road crash occurrence between different road users into a safer, more efficient and environmentally friendly transportation system by incorporating safety features in the road geometric design elements. Thus, road characteristics can greatly help in reducing the frequency of road traffic crashes and contribute to crashes when improperly applied. In general, the condition of the existing roadway characteristics at road segments needs further investigations, particularly in Bole Sub-city.

This study closes the gap by identifying contributions of road geometric parameters on the occurrence of road traffic crashes and develop regression models that can be applied in new design and maintenance of road infrastructures for safety criteria.

1.3 Objectives of the Study

1.3.1 General Objective

The main objective of this study is to investigate the road geometric design elements that cause road traffic crash occurrences at road segments and to model road geometric variables with road traffic crashes in Bole Sub-city.

1.3.2 Specific Objectives

- To study the nature and characteristics of road traffic crashes in Bole Sub-city; and
- To model road geometric variables with road traffic crashes for use in Bole Sub-city.

1.4 Research Questions

The main premise of the study is that the road geometric characteristics that causes road crashes in Bole Sub-city. This study will address issues with several research questions that promise to provide a better insight into the effects of road geometric elements on road crashes in the Sub-city. The main research questions are:

- What is the nature and characteristics of road traffic crashes in Bole Sub-city?
- What is the effect of road geometric variables on crash occurrences?

1.5 Scope and Limitation of the Study

The study focuses on the effect of road geometric design elements on road traffic crash occurrences on road segments of the Bole Sub-city (case study). The study used information of three years from July 2015 to June 2018. Road intersections and roundabouts were not included in the study; rather it is focused on the road segments. Also, road and its environment variables such as land use, posted speed, percentages of heavy vehicles and others were not incorporated. Moreover, the study used average daily traffic (ADT) as exposure variables. However, pedestrian volume is not incorporated in the model. Furthermore, a one-hour counting method was used to calculate peak hour volume.

1.6 Significance of the Study

The investigation has revealed the influence of road geometric characteristics on the occurrence of road crashes. Thus, the significances of the research findings are envisaged to be:

- Road safety authorities, road designers and planners;
- Developing countries like Ethiopia and others with similar road condition and traffic characteristics; and
- Other researchers who are interested to study on related areas.

1.7 Thesis Organization

The thesis is organized into five chapters and have been outlined as follows:

(i) Introduction: It provides overviews at the background of the study, elaborate the statement of the problem, research objectives and questions, the scope and limitation of the study, the significance of the study, and finally, it looks at the thesis organization.

(ii) Literature Review: This section included a review of the relevant theoretical and empirical works that provide a theoretical ground to the study. Thus, a selected research works were compiled to support the research.

(iii) Materials and Methodology: This chapter describes the materials gathered and the methodology applied through which the objectives of research was achieved.

(iv) Results and Discussions: In this chapter, the general analyses of the study is presented and discussed. In addition, model results were explained.

(v) Conclusions and Recommendations: These are presented at the end chapter of the research that summarized the research outputs and forwarded recommendations based on the findings of the study. Finally, the reference used in the study and some other data formats including appendices are attached at the end of the report.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of Road Traffic Crashes

Widely accepted definition of road traffic accidents is given by the Economic Commission for Europe (ECE) that is “road traffic accidents (RTAs) are those accidents that occur on a way or street open to public traffic; resulted in one or more persons being killed or injured, and at least one moving vehicle was involved.” It implies that RTA is collisions between vehicles, vehicles and pedestrians, vehicles and animals and between vehicles and fixed obstacles (ECE, 2005).

The World Health Organization(WHO) defined road traffic crash as “any crash involving a device designed primarily for, or being used at the time primarily for, conveying persons or goods from one place to another”. Alternatively, road crash classified on the basis of the following conditions; the death of a person within 30 days of the crash; or personal injury to the extent that the injured person was admitted to hospital; the crash occurred on any road, street, or any place open to public, the crash involved one or more road vehicles which were in motion at the time of the accident (WHO, 2004). Generally, road crash is an event which is unexpected, undersigned with an element or chance or probability or unfortunate result" and sometimes it is defined as "the occurrence which usually produces injury, death (fatal) or property damage (PDO)". Therefore, it is very essential studying on road geometric characteristics and its environment to reduce traffic crashes by incorporating safety-conscious design and planning of road network and beyond.

2.2 Characteristics of Road Traffic Crashes in Addis Ababa.

Road traffic crashes in the city of Addis Ababa is increasing in alarming rate, which costs human life and economy of the country. Figure 2.1 below shows crash distribution in the city that was developed based on the last seven years from 2010/11 to 2016/17. From the Figure, one can clearly see that the road traffic crash is increasing from year to year for consecutive of seven years without showing any sign of decreasing. The average annual growth rate was calculated at 19.8%.

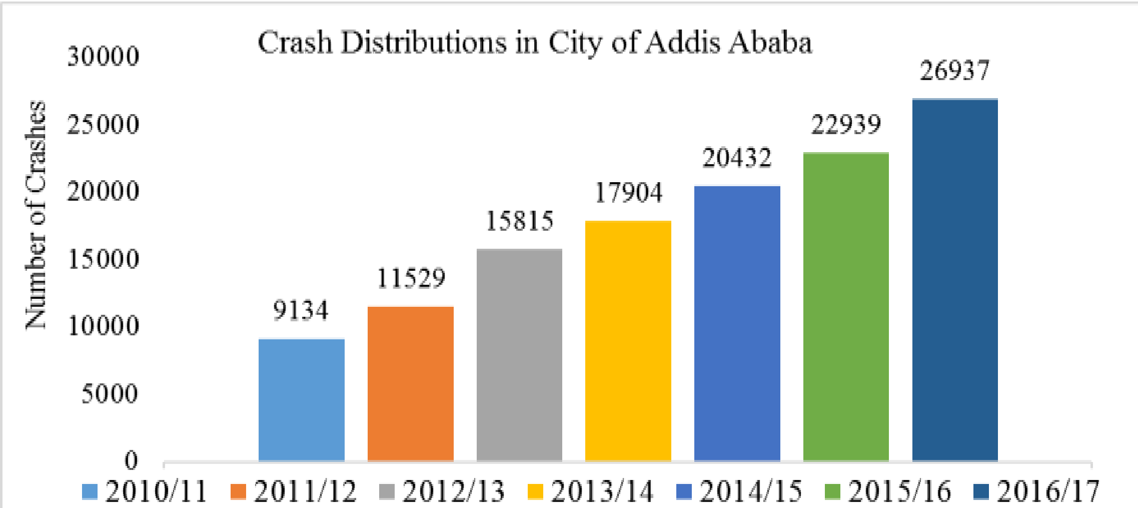


Figure 2.1: Road Traffic Crash Frequency in Addis Ababa

Source: AAPC (2010/11-2016/17).

The FPCE (2012) reports a total of the road crashes of 9,301 in the country during the year of 2007/08 period, about 29% of the total road crashes occurred in the city of Addis Ababa. Road traffic crash in the city of Addis Ababa resulted in significant losses of human and economic resources. In addition, between years of 2000 to 2009 in the city, a total of 25,110 road traffic crashes occurred with about 3,415 fatalities. This indicates, death rate due to road crashes have significantly increased among pedestrians and passengers from time to time. The majority of fatalities were pedestrians (87%) followed by passengers (9%), and drivers (4%).

The research conducted in Addis Ababa by Tariku et al. (2017) showed that out of the road crash data between 2010 and 2014, 14,263 people sustained different levels of crash severity (fatal, severe injury, slight injury) and estimated property damage to be over 19 million US dollars, without costs of injuries for road users. In addition, the findings explained the amount of severity occurred during the course of the five years; 1,911 were fatalities, 6,932 serious injuries and 5,420 minor injuries. Moreover, the researchers showed pedestrians were the most affected (79%) road users, followed by passengers (17%), and drivers (4%).

Another study conducted in the city of Addis Ababa by Alemu (2016) revealed that the frequency of crashes in the city had varied. The study analyzed the percentages of road crash occurrence in three years for 10 Sub-city of Addis Ababa, and found that Bole and Kirkos Sub-cities were leading others, which accounted for 18.5 and 16.4% of total crashes respectively. Accordingly, the highest number of road crashes occurred in Bole Sub-city. The researcher concluded that this was due to its largest area coverage, which contributes to the highest movement of vehicles in the Sub-city and it is the place where the high-income inhabitants are dominantly living. Consequently, more car ownership, a higher traffic and pedestrian volume are generated which creates higher opportunity for road traffic crashes.

2.3 Factors Contributing to Road Traffic Crashes

As incorporated in the report of the Interim National Road Safety Coordination Office and cited in Tulu (2015), the causes for a high number of road traffic accidents have been identified as:

- Lack of driving skills;
- Poor knowledge of traffic rules and regulations;
- Violation of speed limits;

- Insufficient enforcement;
- Lack of vehicle maintenance;
- Animal-drawn carts and animals frequently use main highways;
- Lack of safety conscious design and planning of road network;
- Disrespect to traffic rules and regulations;
- Lack of general safety awareness by pedestrians; and
- Lack of medical facility in general, in relation to accident severity.

These factors are abundant especially in developing countries, and they need deep-rooted solutions since they are associated with road traffic crashes. Generally, the contribution in each set of circumstances falls into the three components of the road traffic system: road environment deficiencies, vehicle defects, and road user errors.

2.3.1 Driver Characteristics

Abbas (2004) developed statistical models forecasting expected number of accidents, and casualties indicated that the main categories contributing to accidents were considered as: drivers, pedestrians, vehicles, road and environmental related factors and others. The study depicts that driver related factor provided to be most of the highly contributing factors, due to loss of control of driving wheel, speeding, stoppage (i.e. sudden stopping).

Nicholas et al. (2001) stated that the main components involved in run-off crashes is the drivers' inability to control both speed and direction. Especially, run-off vehicles occur when a driver is faced with a piece of unexpected (or unusual) information. Causes of this include; the driver's behavior, distractions, the influence of alcohol, drugs (or medication), drowsiness, fatigue, illness, or blackout, speeding, and failure to obey signs, signals or traffic police, which could be due to confusion or unfamiliarity with the roadway.

Chanyukong and Jikuang (2010) investigated the association between the impact of speed and risk of pedestrian causalities in a passenger vehicle collision in China based on real world accident-data. They improved a multiple logistic regression model accepting impact speed observed that the risk of pedestrian fatality is 26% at 50kmph, 50% at 58kmph and 82% at 70kmph. The pedestrians rarely survived at an impact speed of 80kmph.

2.3.2 Vehicle Characteristics

Nicholas et al. (2001) stated that mechanical problems in vehicles are another important factor that contributes to road traffic crashes. Faulty brakes, worn tires, and other vehicle defects affect the controlling of a vehicle, especially at high speeds. Moreover, at high speeds, the tires may blow out leading to loss of control. Tire tread separation is another factor that leads to loss of control. The problems relating to heavy vehicles result from three characteristics: heavy vehicles are much heavier and larger in dimension compared with passenger cars and therefore experience instability and maneuverability problems. In addition, they have less effective acceleration capabilities than passenger cars and have greater difficulty maintaining speeds on upgrades, and this speed variation generates more instances of overtaking and the potential for head-on collisions with oncoming vehicles. Finally, they have a lower deceleration in response to braking than passenger cars, which increases the potential for severe rear-end crashes.

In addition, Abbas (2004) included in his studies that tire burst, vehicle turn off the road and vehicle turn over, and crash due to mechanical failure are considered under vehicle-related factors.

2.3.3 Road Geometric Characteristics

The study conducted on the influence of road traffic management and geometric characteristics on traffic safety in Addis Ababa developed two different statistical regression models using negative binomial regression method for blackspot road segments and non-blackspot road sections. The research found that number of horizontal curve, number of a lane, number of vertical curves, number of access and gradient per kilometer were found to be the main influencing road geometric related variables that significantly affect traffic safety (Tefera, 2015).

Nicholas et al. (2001) stated that the overtaking maneuver on multi-lane roads without the assistance of additional passing lanes is a complex driving task. It requires critical information-processing and decision-making skills, and a lengthy section of road to complete the maneuver. The rate of overtaking crashes are related to the provision and geometric design of passing lanes. When passing lanes are not provided on long sections of road lengths, there is increased potential for risky or misjudged overtaking maneuvers, particularly when sight distance is short. Also, it seems that design practices for passing lanes may not be appropriate for many drivers to pass slow traffic or multiple vehicles in a safe manner.

Moreover, previous studies examined the relationship of crash occurrences in terms of a number of lanes, lane width, and presence of a median, median width, type of median, shoulder width, access density, speed limit, vertical grade, horizontal curvature, and weather condition. The relationship between safety on the highway and factors listed above is the primary focus in crash reduction and predictions (Deo, 2004). In addition, some of the primary geometric design elements that can affect road safety are carriageway, grade, horizontal curvature, shoulder, median, vertical curve (Iyinamet et al., 1997)

Douglas et al. (2000) concluded that geometric design elements play an important role in defining the traffic operational efficiency of any roadway and road traffic accidents. According to the investigation, the key geometric design elements that influence traffic operations and road traffic accidents are number of lanes, widths of lanes, the presence of width of shoulders and highway medians, and the horizontal and vertical alignment of the highways.

The study Conducted by Obaidat and Ramadan (2012) on the traffic accident at 28 hazardous on Amman – (Jordon) urban roads noticed that the logarithmic and linear models were the most important and realistic models that can be used to predict the relationship between the accident characters and dependent variables. According to their studies, the most important contributing factors to traffic accident in hazardous places were ; number of vertical curves, median width, type of road surface, average running speed, posted speed, lighting, number of vehicles per hour, number of crossing facilities, maximum and average degree of horizontal curves and percentage of trucks.

The study conducted in the city of Addis Ababa indicates that land use types had influence on the crash occurrence, and most fatal and injury crashes occurred in CBD and residential areas. Accordingly, 27.7% fatalities and 33.4% serious injuries occurred in CBD and residential areas respectively in the six-year period under consideration and 39.1% of PDO crashes occurred in CBD. Residential, commercial, industrial, and other land uses along roadways are associated with varies number of access to the adjacent properties. However, the number of the road crashes might vary due to the degree of access to the driveways that different land uses faced (Tulu et al., 2013).

2.3.3.1 Road Alignments

Persaud et al. (2000) carried out a separate analysis for tangents and curves, the independent variables were traffic flow and road geometry, while the dependent variable was crash frequency. Regression models have compared the readings with standard readings of a generalized linear modeling. They used a dummy variable for "undulating (or) flat terrain. The Crash frequency for curves was found to increase with AADT, Section length (L) and curvature (1/R). The number of accidents for tangents per year increases with AADT and length. They showed a higher accident number on undulating terrain than on flat one.

Negative binomial distribution used to anticipate crash frequency as a function of the degree of horizontal curvature, section length, lane, shoulder and median widths, AADT, and urban/rural designation. The power of attracting of this study that the models were also to account for driver characters including age and sex. The outcomes have shown that crash frequency increases with AADT, Section length and degree of horizontal curvature whereas, frequency of accident decreases in comparison with lane, shoulder and median width were done by Abdel and Essam (as cited in Kiran et al., 2017).

The relationship among highway geometrics, traffic-related elements, and motor-vehicle accident frequencies were investigated by Milton and Mannering (1998) and found that an increase in the annual daily traffic in the road section tends to increase in road crashes. Moreover, the research concluded that increments in a number of lanes tend to increase road crashes occurrence. The horizontal curve has a strong correlation with the frequency of accidents. They concluded that the radius of a horizontal curve is negatively correlated to road crashes. In addition, they confirmed that horizontal curve not caused by itself to increase accidents but dependent on large straight sections before the curves.

According to Hassan et al. as cited in Mohita (2014) studied on the effect of vertical alignment on driver perception of horizontal curves and found that perception of the driver of the road features ahead is an important human factor and should be addressed in road design. An erroneous perception of the road can lead to actions that may compromise traffic safety and poor coordination of horizontal and vertical alignments are believed to cause such wrong perceptions. Through statistical analysis, they suggested that the horizontal curvature looked consistently sharper when it overlapped with a crest curve and consistently flatter when it overlaps with a sag curve.

Past studies conducted by Ding and PEI (2000) on the study of Shenda Freeway shows, that accident rate and curve radius have a close relationship. Thus, accident rate reduces as the radius of the road increases; and the curves with the same or similar radius are safer than with different radius. A small radius, which is inserted into the long and straight line is dangerous. The study concludes that modification of horizontal alignment is one of the effective countermeasures for highway accidents. Moreover, Glennon(1987) included the relationship of road crashes and curves that suggest that the average crash rate for curved road segments is three times that of tangents, and the average single vehicle's, run-off road crash rate is four times higher.

Sarbaz and Robert(2009) the study conducted on the effect of the curvature on the accident rate revealed that accident rate decreases with increasing radius of curves, for both right and left curves. The investigations also compared left turn and right turn curves road crashes. Accordingly, left turn curves have higher accident rate than right turn curves. Road sections with left curve and radius less than 100 meters have two times accident rate as compared to right curve radius less than 100 meters.

Also, the study revealed road section with a left curve radius of less than 100 m has accident rates that are four times as high as those on a section with curve radius greater than 500 m. Road sections with a curvature of 5 to 10 degree have at least twice the crash rate of sections with a curvature of 1 to 5 degree. Furthermore, sections with a curvature of 10 to 15 degree have crash rates four times as great. Curve radius of 200m seems to be the point below which crash rate greatly increases (Cairney, 1998).

Anderson et al. (1999) relationship between mean crash rate and mean degree of curvature is examined and horizontal curves that require speed reductions had higher crash rates than curves that do not require speed reductions. Curves requiring speed reductions are generally those sharper than about 4 degree, which corresponds to design speeds of less than 100 km/hr. and estimated 85th percentile speeds less than drivers' desired speeds on long tangents (straights). They stated that mean crash rates were similar for degrees of curvature from 0.25 to 4 degree and, 4 degrees as a breakpoint, after which crash rates increased linearly for the remaining intervals 5 degrees and above.

Vertical curves variable were studied as a general risk factor for road crashes. For example, a study of crashes on vertical curves with limited stopping sight distances inferred that the shorter the stopping sight distance, the greater the crash risk. Researchers also described that limited sight distance was not the key problem, rather, it seemed there was a major problem of vehicles stopping in the roadway to make a turn either into a driveway(or access), or turning at an intersection (Kay et al., 2000).

The study conducted by Sarbaz and Robert (2009) on effects of grades on accident rates implied that accident rate on a downgrade is slightly higher than on upgrades, and upgrades have less effect on accident rate while accidents' rate increases with increasing downgrade.

In addition, Iyinamet et al. (1997) studied that the accident rate is highly increasing with increasing of road grades at the point of high slope section. Because emergency braking distance downgrade is longer than that of braking distance upgrade and as a result, more accident occurs at downgrade than upgrade.

The model developed by Gluck et al. (1999) concluded that an increase from 10 access points to 20 access points per mile would increase crash rates by roughly 30%. Moreover, Papayannoulis et al. (1999) found that most studies report an increase in accidents as a result of the increase in a number of driveways. They described that a road with 60 access points per mile would have triple the accident rate compared to 10 access points per mile. Furthermore, Pardillo and Rubio (2003) concluded that access density is one of the highway variables that have the highest correlation with crash rates in Spain´s roads network, and it influences mostly the rate of head-on and lateral collisions. High access density has a negative effect on road safety.

2.3.3.2 Cross-Sectional Elements

Zegeer et al. (1981) studied on the effect of road cross-sectional elements on road traffic accident, roadway cross-section encompasses features on the travel portion of road used by vehicular traffics and the roadside. Accordingly, the design of cross -sectional element influences the safety of the roadway. The portion of the road cross-section normally used for vehicles and pedestrian travel may serve multiple purposes, including future expansion and recovery room for errant vehicles. In addition, types and descriptions for the most Common elements of roadway cross section were given in the following ways; width of the lane, number of a lane, shoulder width, a pedestrian sidewalk in urban, median width, median type and bicycle lane.

Travel lanes: are that portion of the highway intended for use by general traffic. A fundamental feature of roadway cross section is the width of travel lane, which must be sufficient to accommodate the design vehicle, allow for imprecise steering maneuvers, and provide clearance for opposing flow in adjacent lanes. The selection of the number of lanes for a roadway is based primarily on projected traffic volume for the facility.

Sidewalks: Walkways are paved (usually concrete) and separated from the street, generally by a curb and gutter. It is provided mainly in urban areas.

Pathway: Temporary or permanent walkways that may or may not be placed near a roadway and are usually made of asphalt or gravel.

Shoulder: is the portion of the highway immediately adjacent to, and outside of the lanes. In rural or suburban areas where sidewalks and pathways are not feasible, gravel or paved highway shoulder is provided an area for pedestrians to walk next to the roadway. Shoulder is used for emergency stopping, for parking of stopped vehicles, and for lateral support of Sub-base, base and surface course of travel lanes.

Median: is continuous spaces, landscapes, or concrete structures installed in the middle of a roadway for the purpose of separating opposing traffic. Medians are categorized as traversable or non-traversable. Traversable medians are middle lanes mostly known as two-way-left-turn lanes (TWLTL) that are used by left turning traffic to access land-uses.

Non-traversable medians are landscapes, slabs, short concrete walls, or barriers intended to prevent left turning traffic from directly accessing land uses. Curbed concrete or asphalt slabs are the most common types of non-traversable medians on urban arterials and they are known as raised medians. The raised medians are usually used in access management programs to replace TWLTL for the purpose of improving safety and mobility.

Moreover, medians can be categorized into undivided roadway, which is not effective as an access management measure, two way left turn lane (TWLTL) and raised median. Accordingly, the TWLTLs and raised medians are safer than the undivided roadways since road traffic conflicts due to the left turns are reduced from the through traffic lanes. According to Xuecai (2010), TWLTLs improve the operational flexibility by providing a refugee area for vehicles to turn left from both directions. Raised medians limit access and reduce conflict points by separating traffic flow in opposite directions.

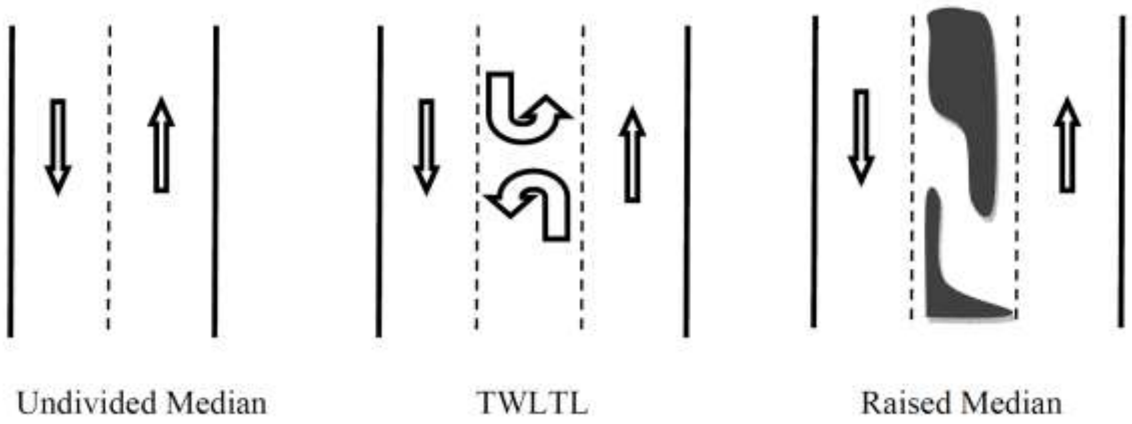


Figure 2.2: Common Types of Medians (Xuecai, X., 2010)

Since drivers on undivided roadways and TWLTLs can make left turns at any point on a roadway, most of the crashes for these two median types are related to left turns. Directional raised medians are used to control left-turn movements. They specify the location for switching from one side of major roadways to the other. Directional raised medians are installed to replace the undivided roadways and TWLTLs because raised medians utilize separate left-turn lanes to limit the locations for making left turns and then reduce the traffic conflicts.

The study conducted by Girma (2004) on relating crash data with traffic volume and the road characteristics by Poisson and negative binomial regression methods depicts that providing median was found prominent in multiple vehicle accident models as well as, pedestrian accident models.

Zegeer et al. (1981) the investigation was conducted on two-lane highway to relate the effect of cross-sectional elements of roads on road traffic crashes and the findings depict that lane and shoulder condition directly influenced runoff road and opposite direction fixed object, rollover, head-on, and sideswipe accident.

A study conducted by Tobey et al. (1983) on the safety effects of sidewalks revealed that sites with no sidewalks or pathways were the most hazardous for pedestrians. This indicates that crashes at sites without sidewalks are more than twice as likely to occur as expected. Thus, sites with no sidewalks were the most hazardous to pedestrians, and sites where sidewalks were present on both sides of the road were least hazardous.

Brain and Robert (1993) investigated the safety effect of a raised curb, TWLTL, and undivided cross-sections on vehicles and pedestrians. A total of 32,894 vehicles and 1,012 pedestrian accidents were analyzed based on 234.8 km (145.9 mi) of unlimited access arterials in three large metropolitan areas. The result of the study found that streets with raised medians in both CBD and suburban areas had lower pedestrian accident rates than TWLTLs and undivided arterials.

In Sub-urban areas, arterials with raised curb medians were found to have significantly lower accident rates than TWLTLs for rear-end, right angle, and left-turn collisions. Raised-curb medians also were found to have significantly lower accident rates than undivided cross-sections for right-angle collisions.

Moreover, the investigation on safety performance for 11 corridors in Texas before and after the installation of access management techniques was done. The data collected in the study included crash rate, access density, traffic volume as well as the presence of 22 raised medians or TWLTLs. It was found that safety improvement was demonstrated on all the corridors after the installation of the raised median (Eisele and Frawley, 2005).

Timur (2010) conducted analysis and evaluation of safety impact of median types and midblock left-turn treatments for urban arterials. The result indicated the segments with RM have lower rear end and sideswipe crash rates by 18.7% and 21.7%, respectively. The reductions in high dangerous crashes such as angle and head on are larger compared to rear end and sideswipe; segments with raised median have lower rates by 37.2 and 39.6% respectively, compared to segments with TWLTL.

A number of access point in urban and suburban areas would affect annual crash rate positively by increasing 0.11 to 0.18 per million vehicle miles on undivided highways and by 0.09 to 0.13 per million vehicle miles on highways with TWLTLs or non-traversable medians. In rural area increase the annual crash rate by 0.07 crashes per million vehicles miles on undivided highways, and 0.02 crashes per million Vehicle miles on highways with TWLTLs or no traversable medians Gluck et al. (1999).

The study conducted in states of Utah and Illinous by Knuiman et al. (1991) on relation of median width and highway accident rate at 982 section of highway (973.8mi) of roadway with 37,544 reported accident over period 5 years in Utah state and 2481 section (2081.3mi) roadway with 55,706 accidents within 4 years in Illinois states. Road section within media width ranging from zero (no median) to 110ft (33.6m) is examined in the study. The result from two states indicated that total accident and rate of specific types and severity decline when median width exceeds about 25 ft. (7.6m).

2.4 Regression Models

Regression analysis is a powerful statistical method that allows examining the relationship between two or more variables. All types of regression analysis at their core examine the influence of one or more independent variables on a dependent variable. Also, the process of performing a regression allows to confidently determining which factors matter most, which factors can be ignored, and how these factors influence each other. The essential terms in the regression are:

Dependent (response) variables: This is the main factor that the investigator is trying to understand or predict.

Independent (explanatory) variables: These are the factors that the researcher hypothesized an impact on the dependent variable (Ben, 2018)

A Study conducted on Safety performance functions incorporating design consistency variables by Alfonso and Lella (2015) stated that generalized linear modelling techniques were used to fit the models and a negative binomial distribution error structure was considered. Explanatory variables considered in the study were; design consistency, horizontal alignment, vertical alignment, sight distance, and roadside context. In addition, the researchers considered natural logarithm of the AADT as an aggregate measure of the traffic volume. They concluded that the ordinary linear model was not appropriate for predicting road traffic crashes because of accident frequency is discrete, and does not follow the normal distribution, which is one of the basic requirements of linear regression technique. Moreover, the variance in the accident frequency is not constant, but tends to increase as the flow increases. The number of accidents also cannot be negative while a normally distributed error structure implies a substantial probability of a negative number of accidents (road crash), especially when the flow is small and the expected number of traffic accidents will also come to small or zero, not negative.

The generalized Poisson regression and the negative binomial regression models have been used to describe count data. Generalized Poisson regression model has an advantage over the negative binomial regression model that it can be used to model count data with either overdispersion or underdispersion. While, the negative binomial regression model is suitable for cases with presence of greater variability (over dispersion). Berhanu (2004) did empirically demonstrated the superiority of the Poisson regression and negative binomial regression over the ordinary linear regression models in analyzing and modeling accident frequencies.

Lund Research Ltd (2015) stated that the Poisson regression technique is attractive in that there is only a single parameter to be estimated but it does have some limitations, especially when the variance of the dependent variable is constrained to be equal to the mean. Road traffic crash as a dependent variable was often found to have a variance greater than the mean, which can result in biased model coefficients and erroneous standard errors. To overcome this problem of overdispersion, the negative binomial regression model is recommended in addition to use a Poisson regression technique.

2.5 Possible Engineering Countermeasures

In the planning, design, and maintenance of the road network, four particular elements affecting road safety have been identified Dinesh et al. (2006). These elements are:

- Safety-awareness in the planning of new road networks;
- The incorporation of safety features in the design of new roads;
- Safety improvements to existing roads;
- Remedial action at high-risk crash sites.

The accident rate was high before safety measures were taken on both upgrade and downgrade but significantly higher accident rate on downgrade than upgrade. However, after safety measures were taken for the highway by increasing two directional lanes, remedial measures were taken to upgrade, and downgrade, and accidents decreased. Again, after installing a speed limit signs, the accidents decreased and kept stable in absolve relatively (Iyinam et al., 2000).

The study conducted in Ethiopia depicts that pedestrians' facilities are not provided adequate manner that exposes pedestrians walking along roads where there are no footpaths, having to cross where there are no facilities, and being at risk at night due to a lack of adequate lighting. While the full provision of pedestrian infrastructure is prohibitively expensive for existing roads, it is possible to incorporate footpaths and crossing points into new roads without a large additional cost. For existing roads, the focus should be placed on locations where pedestrian numbers and risk are highest. For example, pedestrian crashes have often been observed to cluster in urban areas (Tulu, 2015)

At present, engineering treatments for pedestrians are not common practice in DCs, as there is a lack of awareness of the wider economic benefit of these measures, so this area has unexplored potential. One way of addressing this need is through the development of planning guides or manuals for pedestrian facilities in DCs. Pedestrian safety audits on existing and new roads should be conducted (Harwood et al., 2014). Areas that will attract high volumes of pedestrians could be planned not to conflict with major arterial roads and freeways, which would reduce interactions between pedestrians and vehicles. Multimodal transportation planning has potential benefits as well, but requires the engagement of the private sector to deliver efficiency and effectiveness.

The enforcement of compressive and clear legislation with appropriate penalties and creating public awareness can be critical for reducing road traffic crashes and enforcement of road traffic safety law needs to be both improved and sustained. Addressing road safety in a compressive manner necessitates the involvement of multiple sectors such as health, transport and police. A coordinated action between the sectors can bring the solution of road traffic crashes by development and implementation of multi sectoral strategy with sufficient finance for planned action to achieve within a specified period (WHO, 2009).

2.6 Lists of Some Reviewed Literatures

Some list of reviewed literatures used in the study which have been done in national and international levels is presented in Table 2.1 below.

Table 2.1: Summary of Some Reviewed Literatures

Author	Objective	Factors incorporated in the study
Kiran et al. (2017)	A review of road crash prediction models for developed countries	Traffic flow, lane width, number of accesses, speed and road connectors.
Alemu (2016)	Effect of road cross-sectional elements on road traffic crashes and injury severity at midblock(Addis Ababa)	ADT, number of lanes, median type, median width, median height, sidewalk width, and road segment length.
Tefera (2015)	Influence of road traffic Management and geometric characteristics on traffic Safety (Addis Ababa)	AADT, median depression, median width, number of access control, number of intersection with traffic signal, number of intersection with yield sign, number of horizontal curve, number of sharp horizontal curve, surface type, number of lane, number of vertical grade, percentage of heavy vehicles in the traffic stream, posted speed, section length and surface width.

Table 2.1: Summary of Some Reviewed Literatures Continued...		
Author	Objective	Factors incorporated in the study
Obaidat and Ramadan (2012)	Traffic accidents at hazardous locations of urban roads (Jordan)	number of vertical curves, median width, type of road surface, average running speed, posted speed, lighting, number of vehicles per hour, number of crossing facilities, a maximum and average degree of horizontal curves and percentage of trucks.
Zhenyu et al. (2011)	Impacts of access designs and identify contributing factors on crash injury severity at midblock segments (Florida)	ADT, geometric design, land use, environment, and speed limit
Xuecai (2010)	Evaluation of the Safety Impact of Access Management in Urban Areas(Las Vegas)	Length of midblock segments, driveway density, median opening density, median type, land use, traffic flow and number of lanes
Timur (2010)	Analysis and evaluation of safety impacts of median types and midblock left-turn treatments for urban arterials (Las Vegas)	AADT, type of median, number of a driveway, land use, and speed limit
Eisele and Frawley (2005)	Examine the effect of raised median and access density on road safety (Texas and Oklahoma)	ADT, median type, access density, median width and land use
Gluck et al. (1999)	Investigate the impact of access management techniques (New York, Illinois, and New Jersey)	ADT, median treatment, access frequency, and traffic signal density
Milton and Mannering (1998)	Effect of geometrics and roadway characteristics, and motor vehicles accident (Washington)	Horizontal curvature, tangent length, Daily traffic, road section length, speed-limit, roadway width and number of lanes
Brain and Robert (1993)	Investigation of the impact of median on road users(USA)	Median treatment, land use, traffic volume and pedestrian volume

Table 2.1: Summary of Some Reviewed Literatures Continued...		
Author	Objective	Factors incorporated in the study
Knuiman et al. (1991)	Association of median width with highway crash(Utah and Illinois)	Road length, median width and posted speed limit
Zegeer et al. (1981)	Effect of lane and shoulder width on accident reduction on rural, Two-lane road (Kentucky)	Traffic volume, Lane width, shoulder width, and road access point.

In general, the influence of road characteristics on road safety has been studied in developed countries that it is shared significant contribution to road crashes. However, in developing countries, the effect of road characteristics and its significance on road safety is not well investigated. Regards to this, the study aims to investigate on the effect of road geometric design elements on road traffic crash occurrence at road segments in Bole Sub-city.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Introduction

Investigations of the effect of road geometric design elements on road traffic crash occurrences were conducted at road segments in this study. A road segment is a section of a road between two intersections and roundabouts, and between intersection and roundabout without their physical areas. The average radius of the physical area of the roundabout and intersections were estimated 55m from centers of the intersections and roundabouts. Figure 3.1 below shows a midblock segment and it is bounding physical areas of intersections. The safety and mobility in the mid-block segments are influenced by access management techniques, roadway characteristics, traffic flow, and land use (Xuecai, 2010).

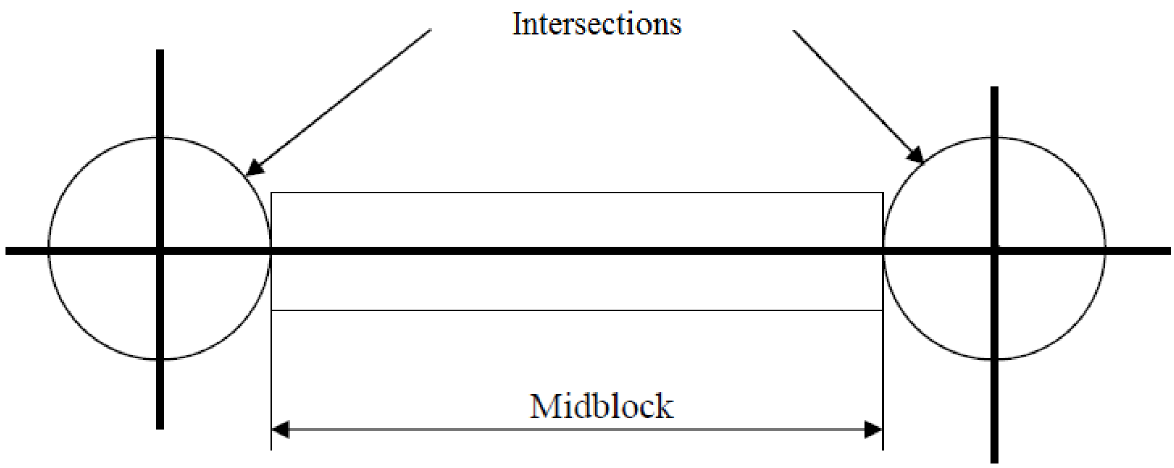


Figure 3.1: Road Segment

3.2 Description of the Study Area

The study was conducted in Bole Sub-city which is located at the South-east part of the city and it is a central business district where the international airport and airport cargo terminal are located. The Sub-city is located at 9^0 0' 57.24"N 38^0 47'59.28"E bordered by Akaki Kality, Nifas Silk Lafto, Kirkos, and Yeka Sub-cities.

Moreover, it is the largest Sub-city in Addis Ababa, which covers a total of 122.08 sq.km. The Sub-city's population density is about 2,817 persons per sq.km with a total population size of 343,856 (SEPAAC, 2013). Figure 3.2 below presents the layout of the Bole Sub-city

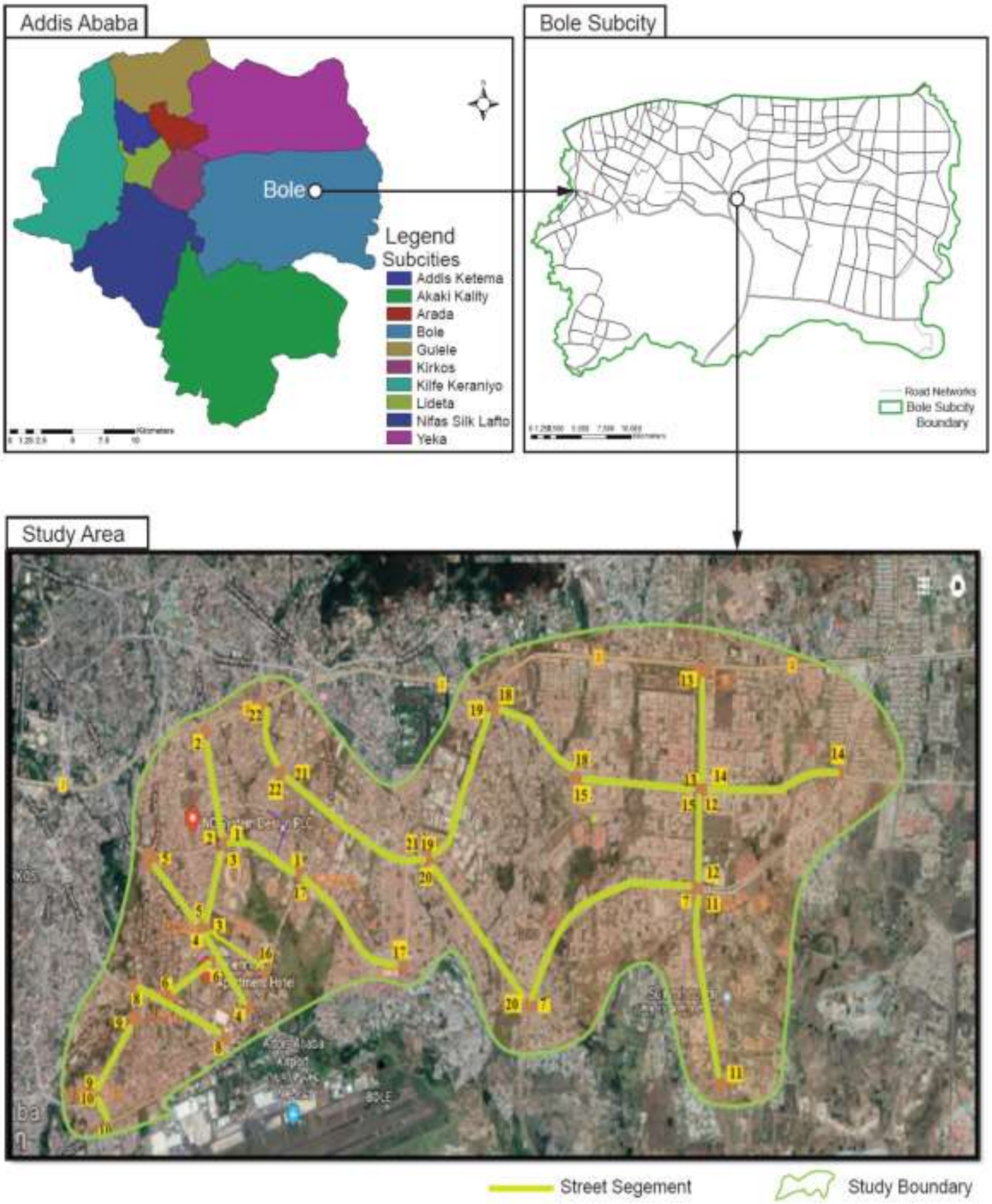


Figure 3.2: Layout for Study Area (Bole Sub-city)

3.3 Sampling Method and Sample Size Determination

Convenience-sampling technique was used during the selection of the samples for the study. The convenience sampling method is a specific type of non-random sampling method that relies on data collection from population members who are conveniently available (i.e. easily accessible) to subjects in a study. To collect the relevant data for investigations, this sampling technique was important that the sampling method comprises of getting contributors wherever you can find them and typically wherever is convenient. In addition to this, uncomplicatedness of sampling and the simplicity of research helpful for model studies and for hypothesis generation, data collection can be facilitated in planned time, and relatively in cost-effective method of gathering data.

The sample size is calculated based on the following formula (Office of Highway Policy Information, 2010).

$$n = \frac{(Cv)^2 (Z)^2}{(d)^2} \tag{1}$$

Where;

n : Required sample size,

Cv : Estimate of variance (at low variance) = 0.1,

d : Desired precision rate or acceptable margin of error for proportion being estimated (= 0.05)

Z : Value of the standard normal statistic for an alpha confidence interval of two-sided = 1.96, 95%.

Accordingly,

$$n = \frac{(0.1)^2 (1.96)^2}{(0.05)^2} = 15.4 \approx 16$$

According to this sample size determination, the minimum sample size of 16 road segments was collected. However, 22 representative sample sizes of road segments for the study were identified and relevant data were collected from road networks located in Bole Sub-city. Selected road segments and gathered data are clearly shown in Figure 3.2 below and in Tables 3.1 and 3.2.

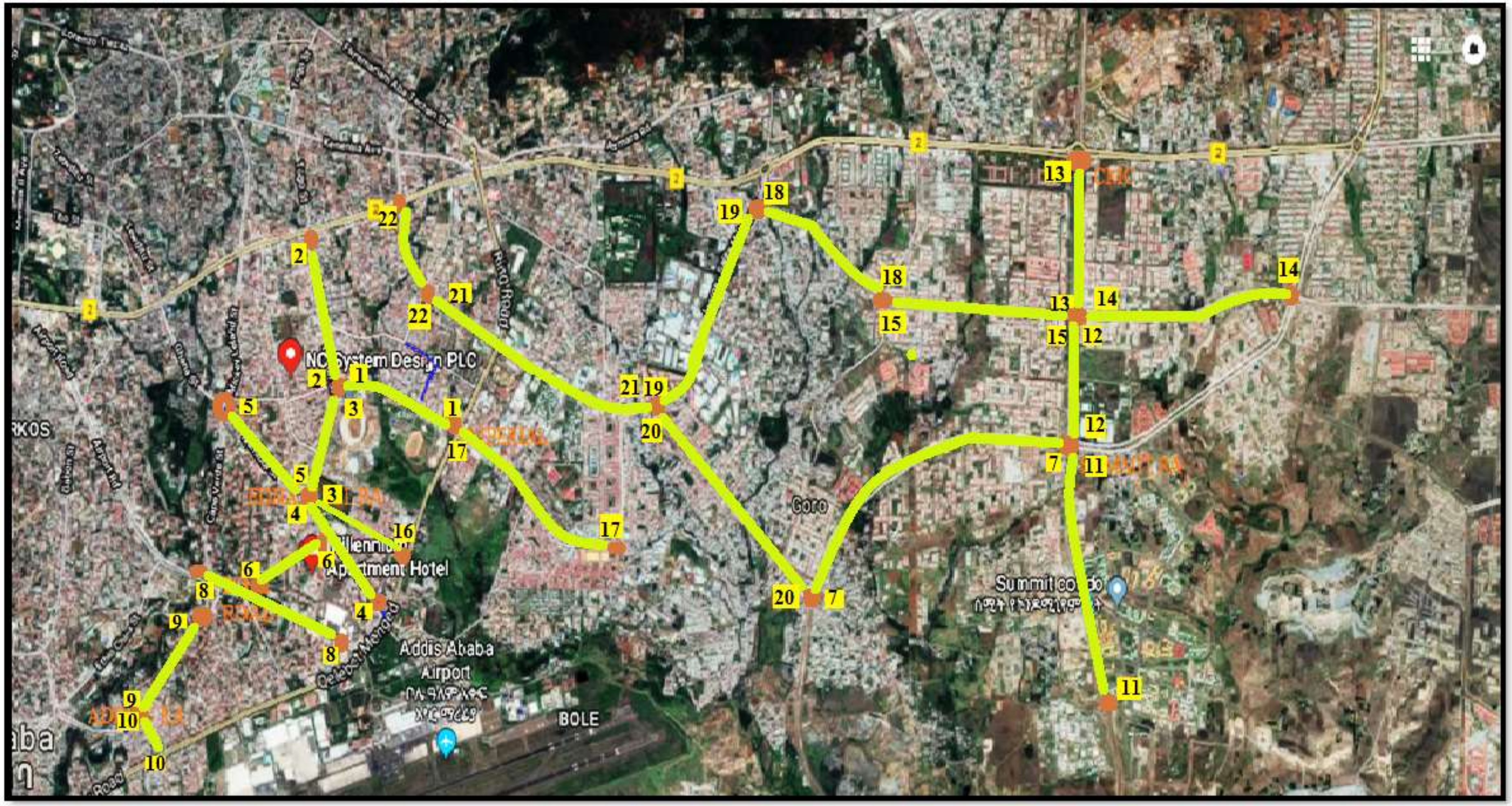


Figure 3.3: Bole Sub-City Selected Road Segments

Source: Google Map Web site (2018)

Table 3.1: Road Geometric Characteristics Variables

No.	Road segment		Variable(A) Road Geometric Elements									
	Start	End	L (m)	NHC	NVC	Gradient	SW (m)	NL	MT	MH (m)	MW (m)	Sidewalk width (m)
1.	Djibouti Road	Imperial Square	1170	1	2	2	18	4	Raised	0.26	0.86	3.50
2.	22 Square	Bole 17 Health Center	1100	2	0	0	9	4	Painted	0	0.15	3.00
3.	Bole 17 Health Center	Edna mall Square	840	3	1	0	10.5	4	Painted	0	0.15	2.90
4.	Edna mall Square	Maternity & Children Hospital, Bole	1130	1	1	0	18	6	Raised	0.9	2.4	3.30
5.	Atlas Square	Edna mall Square	850	1	1	1	18	6	Raised	0.9	2.4	3.30
6.	Bole St.(2000 hall)	Cameron St.	570	1	1	2	10	4	Painted	0	0.15	4.65
7.	Goro Square	Summit Square	2870	1	1	2	14	4	Raised	0.2	35	4.50
8.	Bulbula River	Bole Bridge Square	1650	2	1	0	23	8	Raised	1.3	2.9	4.75
9.	Rwanda Grade Interchange	Addisu Square	960	1	1	0	18	4	Raised	0.2	0.15	2.00
10.	Addisu Square	Bole Michael Square	270	0	4	4	12	6	Raised	0.2	0.2	1.50
11.	Summit Square	Summit Cond. Square	1730	1	0	0	14	4	Raised	0.185	26	4.60

Note; L= Length; NHC = Number of Horizontal Curves; NVC = Number of Vertical Curves; SW = Surface Widths; NL = Number of Lanes; MT = Median Types; MH = Median Height; MW = Median Width.

Table 3.1: Road Geometric Characteristics Variables, (Contd...)													
No.	Road segment		Variable (A) Road Geometric Elements										
	Start	End	L (m)	NHC	NVC	Gradient	SW (m)	NL	MT	MH (m)	MW (m)	Sidewalk width
12.	United Bank S.C Summit Branch	Summit Square	850	1	5	5	14	4	Raised	0.2	23	5.00
13.	CMC Square	United Bank S.C Summit Branch	1070	2	1	1	14	4	Raised	0.2	26	5.00
14.	United Bank S.C Summit Branch	Summit Grade Interchange	1980	1	0	0	20	4	Raised	0.2	0.87	3.50
15.	Young Roots Int. English School	Summit Happy Cafe	1670	0	2	3	20	6	Raised	0.2	0.85	3.00
16.	Edna mall Square	Hayat Hospital	960	2	2	3	10.5	6	Painted	0	0.15	3.50
17.	Imperial Square	Roba Bakery	1800	0	1	1	14	4	Painted	0	0.15	2.50
18.	Jacros St.	Happy Cafe	1370	0	1	1	18	6	Raised	0.2	0.18	1.50
19.	Guard Shola	Jacros Square	1830	2	1	1	18	6	Raised	0.2	0.75	1.85
20.	Jacros Square	Goro Square	1970	1	1	2	18	6	Raised	0.18	0.95	3.60
21.	Mother Restaurant	Jacros Square	1880	1	3	4	20	6	Raised	0.15	1.5	4.70
22.	St. Equatorial Guinea	Mother Restaurant	850	1	1	1	20	6	Raised	0.35	0.2	4.00

Source: Primary data collected from the selected road segment by the author, 2018

Table 3.2: Other Control Points and Dependent Variable

No.	Variable (B) Other Control Points				Variable (C) Crash Severity			
	Number of accesses	Number of access controls	Surface Types	ADT	Fatalities	Injuries	Property damages only	Total crash occurrence
1	18	1	Asphalt	16,619	1	35	279	315
2	18	0	Asphalt	16,310	4	34	272	310
3	7	0	Asphalt	16,471	1	25	254	280
4	12	0	Asphalt	16,276	3	20	227	250
5	20	0	Asphalt	16,238	3	42	262	307
6	4	0	Asphalt	8,881	5	23	208	236
7	10	0	Asphalt	18,933	15	50	245	310
8	11	0	Asphalt	41,662	10	50	272	332
9	7	0	Asphalt	18,848	4	35	198	237
10	5	0	Asphalt	13,590	7	49	254	310
11	8	4	Asphalt	17,724	5	30	136	171

Note; ADT= Average Daily Traffic

Table 3.2: Other Control Points and Dependent Variable, (Contd...)								
No.	Variable (B) Other Control Points				Variable (C) Crash Severity			
	Number of accesses	Number of access controls	Surface Types	ADT	Fatalities	Injuries	Property damages only	Total crash occurrence
12	7	2	Asphalt	18,629	3	22	136	161
13	7	0	Asphalt	17,871	4	17	153	174
14	6	2	Asphalt	15,657	1	22	141	164
15	6	0	Asphalt	19,795	3	16	120	139
16	6	0	Asphalt	10,776	5	28	210	243
17	26	0	Asphalt	18,081	9	61	397	467
18	5	0	Asphalt	17,143	5	10	135	150
19	10	0	Asphalt	21,005	9	52	327	388
20	18	3	Asphalt	21,629	17	36	213	266
21	20	3	Asphalt	33,267	4	50	332	386
22	6	2	Asphalt	17,990	3	33	193	229
Sum	237	17		413,395	121	740	4964	5825

Source: Primary (other control points) and Secondary data (crash severity) on the road section by the author, 2018

3.4 Data Collection

For this study, two type of data were collected. The first one was road and road environment and the second one was traffic volume data that the author directly collected through measurement from the selected road segments. The other was data that the Addis Ababa Police Commission and Bole Sub-city Traffic Police Station used for official reporting of road traffic crashes at end of the year. It includes, crash severity (severe injury, slight injury and property damage) happened on the Bole Sub-city road network for each road crashes. Traffic police provided detail information of the crashes such as; crash location, time, date, causes, road users involved in crashes, vehicle maneuver, and road geometric characteristics and other necessary information.

3.4.1 Road Crash Data

Road traffic crash data were collected from the Bole Sub-city Police Station from July, 2015 to June, 2018 that occurred at selected road segments. However, fatal crashes data and summarized crash data were collected from the Addis Ababa Police Commission between the same years. The crashes registered for three years were in hardcopy and it includes time of day, day of the week, education, age and gender of drivers, driving experience, driver's relationship with vehicle, vehicle service years, vehicle type, vehicle ownership, road type, median and junction types, terrain, pavement type, pavement conditions, illumination, weather conditions, casualty type, causes for the crash and crash locations. The data gathered were a prepared manually and transferred into an Excel file format for the crash frequency analysis.

Figure 3.4: Collecting Road Traffic Crashes Data
(Bole Sub-city Traffic Police Station)

3.4.2 Traffic Volume Data

Traffic volume data were used as input to undertake analysis. This study used local short-duration (peak hour) counts method from 7:30 a.m. to 8:30 a.m. for seven days from twenty-two selected road segments to estimate daily traffic. Vehicles were classified in the study; car, station wagon (4WD), small bus, large bus, small truck, medium truck, heavy truck, and articulated truck in reference to the Ethiopian Roads Authority (ERA) 2000 vehicle Classifications. To convert average daily traffic into a peak hour volume, the ADT was multiplied by a K factor which is 0.12 (12%) in case of Addis Ababa. Therefore, to get ADT peak hour volume divided by K factor is formulated as follows (Girma, 2004):

$$ADT = \frac{PHV}{K} \quad (2)$$

Where; ADT: Average Daily Traffic, PHV: Peak Hour volume and K: K factor

3.4.3 Road and Road Environment Data

Road geometric characteristics such as road segment length, number of horizontal and vertical curves, number of down and upgrade, number of lanes, surface width, median type, median width, median height, sidewalk width, were collected directly through actual measurement from selected road segments in Bole Sub-city. In addition, other road environment data such as number of access and access control, and surface type were included in the study.

Figure 3.5: Raised Median Width Data Collection
(Summit Grade Interchange St.)

3.5 Candidate Variables Identification in the Model

The main target of getting effective parameters was to select influencing variables with the available data to develop a more realistic model. The effective explanatory and exposure variables that influence the road traffic crashes was evaluated by statistical analysis method. Table 3.3 shows the independent candidate variables (major road alignment and cross-section) suggested for the crash prediction model. The main road characteristics used for the analysis are described in the following sections.

Road traffic crash frequency is defined as the number of crashes occurring within a specific jurisdiction, on a roadway segment, or at an intersection. A number of road traffic crashes is used as a response variable (or dependent) variable.

Traffic volume is the number of vehicles that pass a given point on the roadway in a specified period of time. The average of the seven days counts is considered as average daily traffic (ADT) which is primarily computed from peak hour volume and k factor in this study. The K factor is defined as the proportion of average daily traffic occurring in an hour. This factor is used for designing and analyzing the flow of traffic on highways.

Peak hour volume is the maximum number of vehicles that pass a point on a highway during a period of 60 consecutive minutes. By counting the number of vehicles that pass a point on the roadway for a duration of an hour (15-minute interval); it is possible to arrive at the 15-minute maximum volume. Then, 15 minute (quarter volume) is converted to peak hour volume.

Number of access (Access density) refers mainly to the number of driveways within a roadway segment. Access density is one of the factors that has been pointed out as the determinant of accident rates on the highways. It includes exit and entrance ramps, cross roads and other accesses to residential areas, commercial centers, offices, etc.

Access Control: Access control techniques includes; traffic control devices, signs, guardrail, fences, and so on. It is used to improve traffic performance and safety on highways.

Horizontal curves: Horizontal curve is one of the major road alignment that influences road safety. The number of curves per section of road is counted for basic accident prediction variable. Moreover, both sharp and non-sharp horizontal curves are included in modeling process.

Vertical curves: Vertical curves are also basic and influential parameter of road geometric alignment on the road safety which includes both crest and sag curves and it is considered as a candidate variable for regression analysis in this study.

Median type: Median type also is a safety parameter, and in this study, it was considered as categorical variable and assigned as raised and painted median types.

Median width: median width is one among the road cross-sectional elements, and taken as a candidate variable in the modeling process on the selected road sections.

Surface width: As depicted in the general descriptive crash analysis, different Pavement condition has different magnitude of traffic crashes. It is one of the contributing factors to speeding of vehicles that lead to road traffic crashes. Because of the selected study sample, road sections were asphalt (flexible pavement) with good conditions, that missed other types of pavement conditions to correlate with crash frequency, it is removed as a reason of its being statistically insignificant.

Length of road segment: The study was conducted on different roadway section lengths in Bole Sub-city and road length is one among the explanatory variable used in traffic safety analysis of the modeling process.

Vertical gradient: Both upgrade and downgrade count per section of road segment were included in this study.

Number of lane: lane is a longitudinally marked part of road cross-section that is wide enough to accommodate one vehicle. For this study, number of lanes is considered for accident frequency modeling process.

Sidewalk: It is also known as foot path or footway, is a path along the side of a roads. In this study, only one side of road data is considered as candidate variable for the modeling process in the traffic accident analysis.

Median height: Median is central reservation that might be either raised or painted. Hence, median height data measurement is taken for twenty-two road segments for both raised and painted median for the road crash prediction model.

Table 3.3: Candidate Variables Considered in the Modeling Process

Variable	Description
SEC_LENGTH	Length of the road segment in meter
NUM _HC	Number of horizontal curves per road segment
NUM _VC	Number of vertical curves per road segment
NUM_V_GRAD	Number of vertical grades per road segment
SURF_WIDTH	Width of the road surface in meter
NUM_LAN	Number of lane on road segment
MED_TYPE	= 1 if the median is a raised, = 0 otherwise (painted)
MED_WIDTH	Average width of the median in meter
MED_HEIGHT	Average height of the median in meter
SIDWK_WIDTH	Width of the sidewalk in meter
NUM_ACCESS	Number of access per road segment
NUM_ACC_CONTROL	Number of access control per road segment
ADT	Average daily Traffic on road segment

From those proposed candidate explanatory variables for the modelling, some of them were excluded from the model by statistical analysis, and only statistically significant variables were incorporated in the model development.

3.6 Development of the Multivariate Models

Crash count statistical modeling techniques is used to know the relationship between dependent variables and independent variables. This includes both Log-linear Poisson Regression Model and Negative Binomial Regression Model, which the study used to associate road geometric variables with road traffic crash occurrences. The estimated coefficients of the variables were tested to develop the final model. Statistically insignificant explanatory variables were systematically removed from the model and then, interpretation for those statistically significant variables were done.

Statistical significance was evaluated at a p-value of 10%. Figure 3.7 below illustrates model development process in the study. In addition, the descriptive analysis of the general crash trends in the Bole Sub-city was organized and analyzed using Microsoft Excel and were presented in the forms of tables, charts, and graphs.

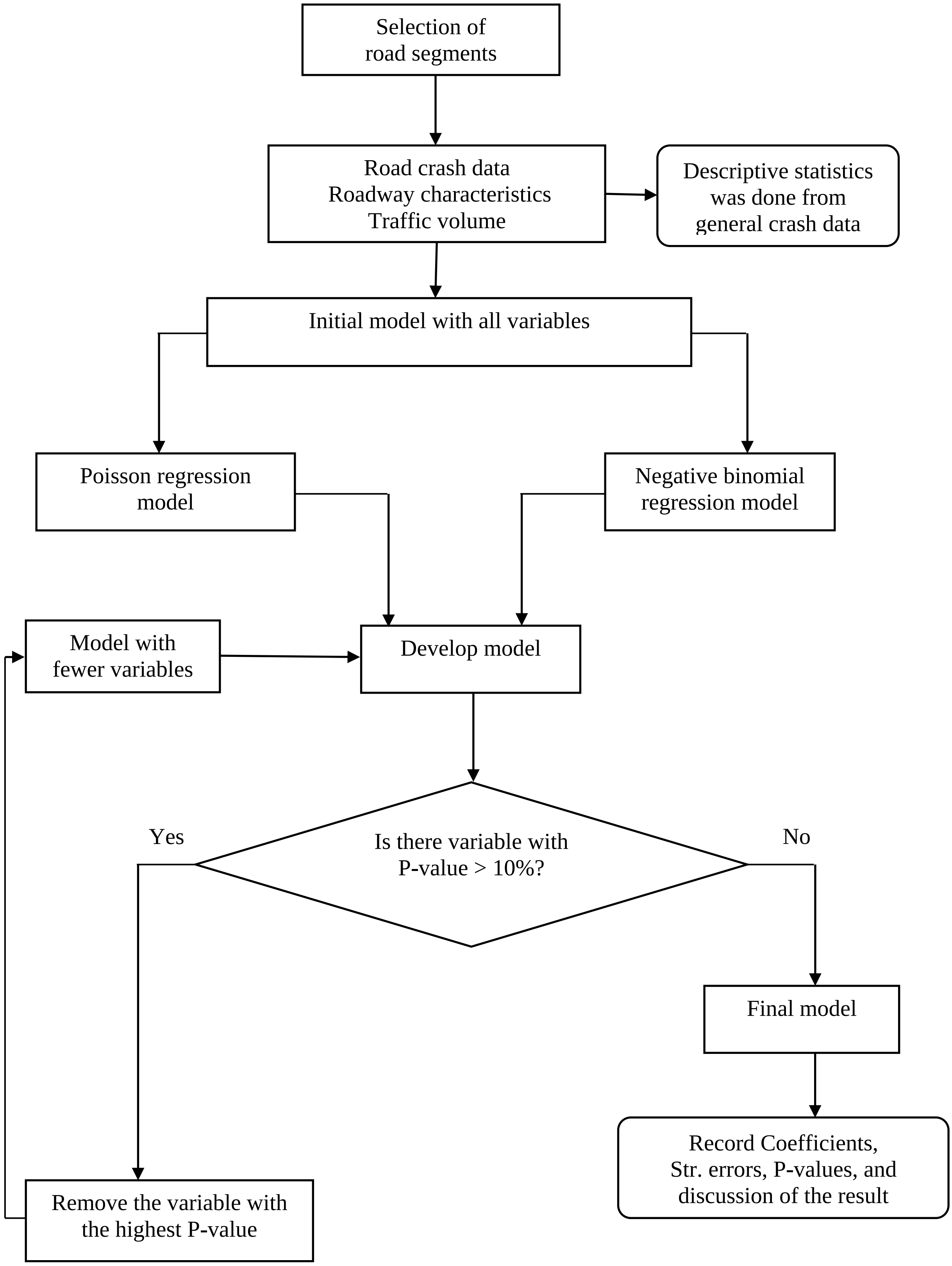


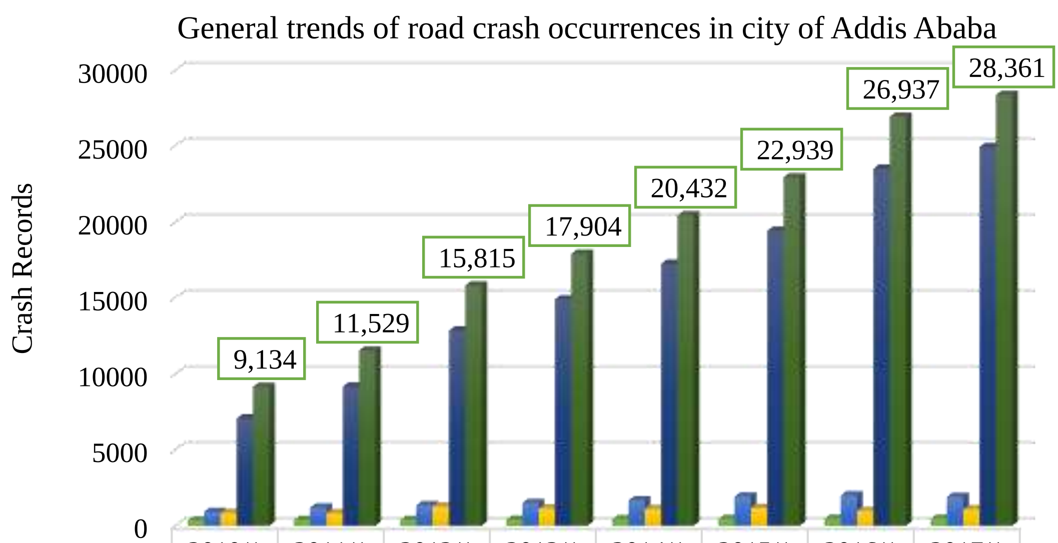
Figure 3.6: Model Development Process

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Road Traffic Crashes Trends in Addis Ababa

Figure 4.1 below gives information about crash records of general trends of crash occurrence in the city of Addis Ababa over the last eight years (2010/11 to 2017/18). The average annual growth rate was calculated at 17.6%. The figure also shows that the general trends of road traffic crash occurrence in the city of Addis Ababa has been increasing from year to year.



	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Fatality	332	369	367	391	416	439	458	456
Severe injury	904	1190	1336	1484	1669	1924	1996	1903
Slight injury	831	820	1263	1128	1098	1165	973	1074
PDO	7067	9150	12849	14901	17249	19411	23510	24928
Total Crahes	9,134	11,529	15,815	17,904	20,432	22,939	26,937	28,361

Figure 4.1: General Trends of Road Traffic Crashes in Addis Ababa

Source: AAPC (2010/11-2017/18) Computed by the Author, 2018

4.2 General Analysis of Road Crash Trends in Bole Sub-City

The author extended three years before the study time frame to show more accurate general trends of crash frequency in Bole Sub-city over the last six years from 2012/13 to 2017/18. Accordingly, about 2862 (11%), 3229 (13%), 3679 (15%), 4458 (18%), 5404 (21%) and 5686 (22%) road traffic crashes occurred in the Sub-city in years 2012/13, 2013/14, 2014/15, 2015/16, 2016/17 and 2017/18 respectively (Figure 4.2). It can clearly be seen that the crashes were significantly increased yearly in these intervals of time.

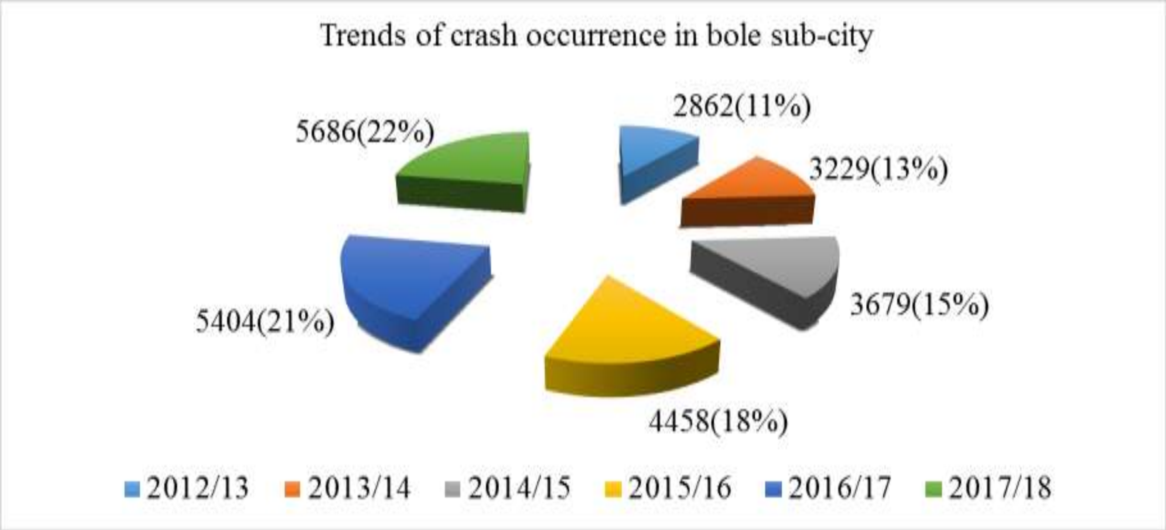


Figure 4.2: Road Traffic Crash Trend in Bole Sub-city
Source: BTPO and AAPC (2012/13-2017/18) Computed by the Author, 2018

Comparably, the total road crashes that occurred in Addis Ababa City (10 Sub-cities) from 2012/13 to 2017/18 were 132,388, and that of the Bole Sub-city was 25,318, including property damages. During this time, about 19.12% of road traffic crashes occurred in Bole Sub-city. Hence, Bole Sub-city shared high road crash frequency in the city. Therefore, this is why studying the possible influencing factors for traffic crash in the Sub-city and recommending a mitigation measure is not an option but a must for road traffic professionals.

The nature and characteristics of traffic crashe occurrences in the Sub-city were used as the general guidance for the interdependence of road traffic crashes and the road characteristics for the later detail analysis and correlation between them.

4.2.1 Causes of Road Traffic Crashes

There are many causes of road traffic crashes according to the traffic police road crash investigation team reports. Accordingly; drunk driving, drug driving, driving without respecting the right hand rule, failure to give-way for the other vehicles, failure to give-way for pedestrians, tailgating, overtaking on crust vertical curve, overtaking on winding horizontal curve, improper turning after overtaking, driving above speed limit, improper overtaking, improper turning, not respecting traffic rules, not respecting traffic light and others. Major causes of road traffic crashes for the consecutive of three years 2015/16-2017/18 were; tailgating (45.3%), failure to give-way for the other vehicles (22.2%), and failure to give-way for pedestrians (7.6%); whereas, some other factors had almost negligible contribution to crashes (drink driving, drug driving, overtaking on crust vertical curve, overtaking on winding horizontal curve, improper turning after overtaking not respecting traffic sign and others. However, the traffic police have limited road and traffic engineering skill in developing country. Consequently, they underestimated the contribution of roadway to traffic crashes and especially their lack of trainings on subject area. As depicted in Table 4.1 below the causes of road traffic crashes were generally classified into human factors; related to driver, passenger, and pedestrian which accounts about 93.5% of the total crashes (i.e. main causes of road crashes) and non-human factors; those factors related to weather conditions, road characteristics and mechanical defects of vehicles, which accounts only 1.6% of total crashes. Furthermore, other causes of road crashes that are not mentioned were about 2.6% and unidentified causes of crashes estimated (2.4%) were included in the report.

Table 4.1: Causes of Road Traffic Crashes

No.	Causes of road traffic crashes	Fatal	Serious Injury	Slight Injury	PDO	(%)	
1	Drunk driving	1	-	-	-	0	93.5% (due to Human Error)
2	Drug driving	-	-	-	-	0	
3	Driving W/t respecting right hand rule	6	1	-	1	0.1	
4	Failure to give-way for vehicle	14	-	-	3440	22.2	
5	Failure to give-way for Pedestrian	149	823	213	-	7.6	
6	Tailgating	25	-	1	7013	45.3	
7	Overtaking on crust vertical curve	1	-	-	-	0	
8	Overtaking on winding horizontal curve	-	-	-	-	0	
9	Improper turning after overtaking	-	-	-	-	0	
10	Driving above speed limit	-	-	-	301	1.9	
11	Improper overtaking	-	-	-	141	0.9	
12	Improper turning	-	-	-	778	5	
13	Not respecting traffic rules	-	7	1	1113	7.2	
14	Not respecting traffic light	-	-	-	16	0.1	
15	Not respecting traffic Sign	-	-	-	-	0	
16	Not respecting give way traffic sign	1	-	-	239	1.5	
17	Improper movement from stoppage	1	-	-	52	0.3	
18	Improper stoppage	-	-	-	66	0.4	
19	Driving with fatigue	-	-	-	-	0	

Table 4.1: Causes of Road Traffic Crashes, (Contd....)							
No.	Causes of road traffic crashes	Fatal	Serious Injury	Slight Injury	PDO	(%)	
20	Driving without attention	-	-	-	-	0	Part of human factor
21	Excess light	-	-	-	-	0	
22	Excess loading	-	-	-	130	0.8	
23	Pedestrian failure to respects traffic rule	1	-	-	-	0	
24	Mechanical failure of vehicle	1	1	-	242	1.6	1.6%
25	Due to road characteristics	-	-	-	-	0	
26	Others	2	249	88	64	2.6	2.6%
27	Unknown	17	70	16	263	2.4	2.4%
Total		219	1151	319	13859	100	

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.2 Victims of Road Traffic Crashes

As shown in Table 4.2 below victims of road traffic crashes for consecutive of three years were; pedestrians, passengers and drivers. Accordingly, out of the total road crash occurrences for these years, 76.3% of the victims in the city were pedestrians that represented for the highest proportion of the crashes. On the other hand, passengers and drivers shared 16.6% and 7% of the road crash frequency happened in the city respectively. In addition, more than 80% of the victims were in the productive class of the society (18 and 50 years). Consequently, the road traffic crashes adversely affect the economy of the country. Generally, pedestrians and passengers shared about 93% of road traffic crashes (highest proportion of total crashes) while drivers account for a small share of crashes.

Table 4.2: Crash Severity by Road User Distributions

Road users	Age	Crash Severity(2015/16-2017/18)					
		Fatal	Serious	Slight	Total	Percentage	
Driver	< 18	1	1	-	2	0.1	7%
	[18-30]	5	41	4	50	3	
	[31-50]	6	33	14	53	3.1	
	>50	1	13	0	14	0.8	
Pedestrian	< 7	7	2	0	9	0.5	76.3%
	[7-13]	11	13	5	29	1.7	
	[14-17]	10	43	21	74	4.4	
	[18-30]	63	391	137	591	35	
	[31-50]	47	360	51	458	27.1	
	>50	33	80	15	128	7.6	
Passenger	< 7	1	-	-	1	0.1	16.6%
	[7-13]	4	2	-	6	0.4	
	[14-17]	3	16	13	32	1.9	
	[18-30]	10	102	43	155	9.2	
	[31-50]	11	45	15	71	4.2	
	>50	6	9	1	16	0.9	
Total		219	1151	319	1,689	100	

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.3 Crashes by Days of Week

Average crashes that occurred during days of week were about: 837, 808, 767, 706, 757, 788, and 520 on Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday respectively.

Table 4.3: Accident Ratios by Days

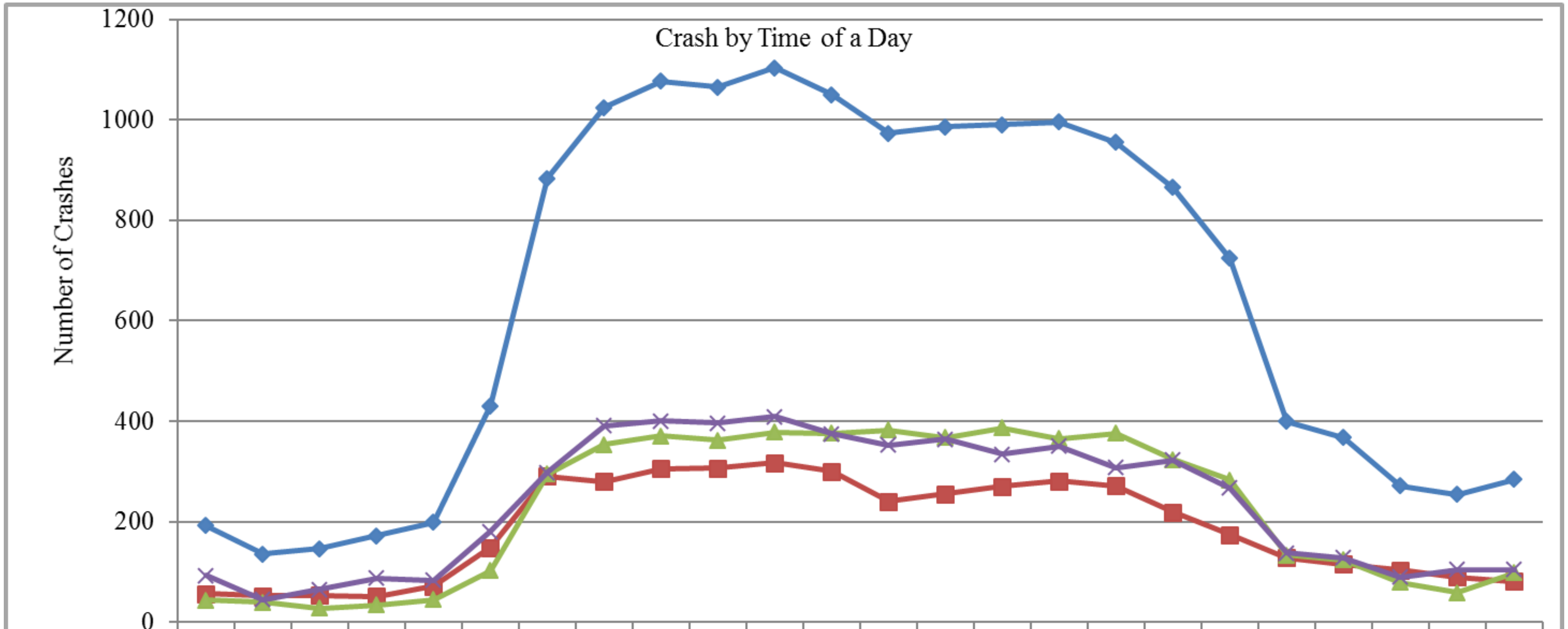
Day	Average Number of Accidents	Ratio
Monday	837	1.61
Tuesday	808	1.55
Wednesday	767	1.48
Thursday	706	1.36
Friday	757	1.46
Saturday	788	1.52
Sunday	520	1.00

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

As shown in Table 4.3, the lowest number of accidents occurred on Sunday with 520 and the highest on Monday. Regarding ratios, the Monday accidents were about 1.6 times that of Sunday followed by Tuesday which was 1.55 times that of Sunday. Hence, the highest number of road traffic crashes occurred on Monday followed by Tuesday. This might be due to Monday is a starting of workdays after weekends. For this reason, most of the people did not want to stay at home on this day. Consequently, the streets in the city are congested particularly during peak (rush) hours relating with other working days. As a result, higher number of crashes is expected on Mondays. Road traffic crash is found to be relatively lower on Sunday and Thursday. Sunday is non-working day for most of governmental and private offices. Hence, low movements of vehicles, passengers, and pedestrians occurred on the days compared to other days.

4.2.4 Crash Variations by Time of a Day

Times of days have different crashes frequency depending on activity of the people, the traffic situation, road users’ conditions and work time rules, and the others. Figure 4.3 depicts total daily crash that happened during different hours of a day. The streets were relatively safe from 8 p.m. to 5 a.m. A total number of crashes peaked between 7:00 to 18:00 (7am to 6pm) during daytime in the same conditions in the consecutive of three years. During these times, road users are active on the streets. Hence, high conflict between them is expected that might result in road crashes. The density of traffic on the streets also affects average vehicle speed and hence, prevalence and outcome of the crash. During daytime, density of traffic is high and therefore, higher number of road crashes would have happen.



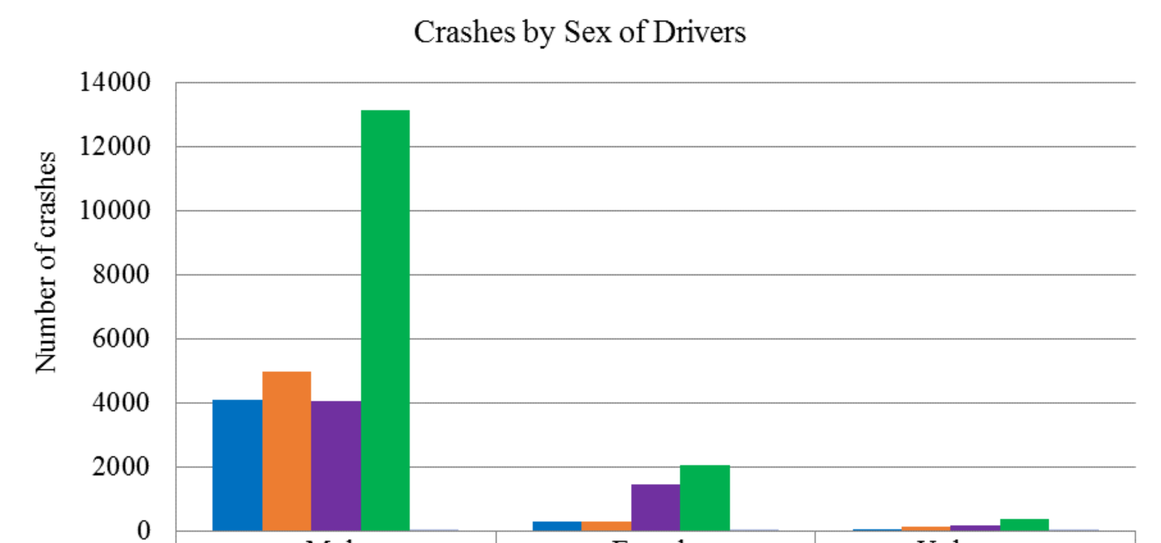
	0100-0200	0200-0300	0300-0400	0400-0500	0500-0600	0600-0700	0700-0800	0800-0900	0900-1000	1000-1100	1100-1200	1200-1300	1300-1400	1400-1500	1500-1600	1600-1700	1700-1800	1800-1900	1900-2000	2000-2100	2100-2200	2200-2300	2300-2400	2400-0100
2015/16	56	52	53	51	71	148	291	280	305	307	317	300	240	255	270	281	271	219	174	128	115	103	90	81
2016/17	43	39	28	34	45	102	295	354	371	362	378	376	382	367	387	365	376	324	283	133	124	79	59	98
2017/18	93	45	65	87	83	180	298	391	401	396	409	375	352	364	334	350	308	323	267	138	128	89	105	105
Total	192	136	146	172	199	430	884	1025	1077	1065	1104	1051	974	986	991	996	955	866	724	399	367	271	254	284

Figure 4.3: Road Traffic Crashes by Time of a Day

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.5 Distribution of Road Accidents by Gender

The occurrence of gender-related road crash significantly varied in the Bole Sub-city. Accordingly, about 84.4% of road traffic crashes happened by male drivers, which put their life and others in dangers. However, only 13.2% of total crash occurrence was shared by female drivers. About 2.4% of the total crashes were not identified to either of the sexes. Figure 4.4 below clearly shows the general distribution of road crashes by gender recorded in the Sub-city in consecutive of three years.



	Male	Female	Unknown
2015/16	4103	282	73
2016/17	4984	288	132
2017/18	4042	1475	169
Sum	13129	2045	374
Percent	84.4%	13.2%	2.4%

Figure 4.4: Distribution of Road Crashes by Gender

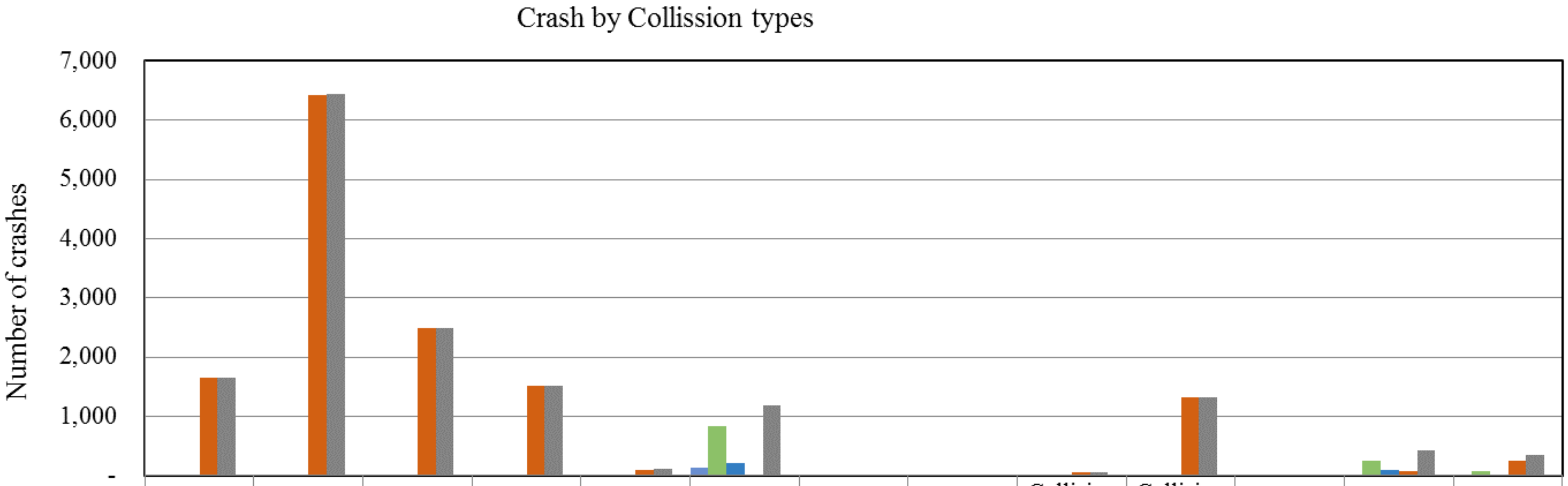
Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.6 Road Traffic Crashes by Collision Type

Different type of collisions and percentage of road traffic crash by collision types and crashes severity occurred in consecutive of three years in Bole Sub-city as illustrated in Figure 4.5. These collision types were; head-on crashes rear-end crashes, angle crashes, sideswipe crashes, rollover, collision with pedestrians, collision with animals, fall from vehicles, collision with parked vehicles, collision with a fixed object and crashes with a train.

From the analyses the percentages of these collisions types constitutes; rear-end collision (41.4%), angle crash (16%), head on crashes (10.6%), sideswipe collision (9.8%), roadside (8.5%), and collision with pedestrian (7.6%) were the most dominant type of collisions which frequently occurred in the Sub-city. However, others collision types like collision with vehicle parking (0.3%), rollovers (0.7%), others (2.7%) and unidentified collision types (2.3%) had relatively low number of accident.

Moreover, collision types like collision with animals, fall from vehicles and collision with train had insignificant effects on road crash occurrences in the Sub-city. Analyzing various types of collisions in traffic crash is important point to identify the main causes and possible countermeasures with relation to quick traffic management related issues. Collision with pedestrians and rollover were the major causes of fatalities occurred in the Sub-city.



	Head on Crashes	Rear End Crashes	Angle Crashes	Side Swipe Crashes	Rollover	Collision with Pedistrian	Collision with Animals	Fall from Vehicles	Collision with Parked Vehicles	Collision with Fixed Object	Crashes with Train	Other	Unknown
Fatal	11.00	9.00	5.00	6.00	19.00	140.00	3.00	1.00	3.00	4.00	-	6.00	12.00
Seroius Injury	0	0	0	0	0	824	0	1	0	0	0	256	70
Slight Injury	0	0	0	0	0	214	0	0	0	0	0	89	16
Property damage	1641	6425	2486	1515	96	0	0	0	50	1324	1	65	256
Total	1,652	6,434	2,491	1,521	115	1,178	3	2	53	1,328	1	416	354
Percent	10.6%	41.4%	16.0%	9.8%	0.7%	7.6%	0.0%	0.0%	0.3%	8.5%	0.0%	2.7%	2.3%

Figure 4.5: Total Road Traffic Crash by Collision Types

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.7 Crash by Road Alignment

The road geometric alignments have significant impact on road traffic crashes. As depicted in Table 4.4 below, the major road geometric alignments categorized as straight and levelled, vertical curves, horizontal curves, upgrade and downgrade. The highest road traffic crashes were recorded on straight and levelled road with percentage of 94.5%, and followed by horizontal curves 4.7% and vertical curve (i.e. crest and sag vertical curve) constitutes of 0.42%. Speed could be main reason for road traffic crashes happened on straight and levelled road alignments. From the analysis of police recorded traffic crash data it has clearly indicated that road geometric alignments like horizontal curve, vertical curves were the main road alignments where the frequent road traffic accidents occurred. However, crash frequency on road gradients (i.e. upgrade and downgrade) consists of lower percentages.

Table 4.4: Road Traffic Crashes by Road Alignment

Road alignment	Total	Percentage (%)
Tangent road with flat terrain	14,562	94.5
Vertical curve	227	0.42
Horizontal curve	726	4.7
Upgrade	6	0.12
Downgrade	3	0.1
Unknown	24	0.14
Total	15548	100

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.8 Road Traffic Crashes by Road Junction Type

Road crash frequency by road junction type in year between (2015/16 to 2017/18) is shown in Table 4.5 below road junctions are categorized into different types including: midblock (road segment), Y-junction, T-junction, roundabout, four-leg junction (or +) junction, X junction, and rail crossing with their respective percentage of crash frequency;

95.8%, 0.1%, 0.2%, 3.2%, 0.6%, 0%, 0% and 0.1% respectively. Mid-block road sections has the highest and most frequent accident rates as compared to the other junctions. This is probably due to much pedestrian crossing takes place in these sections. Lack of adequate pedestrian crossing facilities in midblock areas that might result in increased road traffic crashes. Also, vehicle speed is expected to be high at road segments which increase road traffic crashes occurrences. The other types of junction like roundabout, and four-leg junction (+) have optimum level of accident occurrence whereas, T-junction, Y-junction had low accidents in the Sub-city. Furthermore, X junction, and rail crossing rail-crossing junction types were insignificantly contributed to road crash occurrence in the Sub-city.

Table 4.5: Road Traffic Crash by Road Junction Type

No.	Road Junction	Fatal	Serious Injury	Slight Injury	Property damage	Percentage (%)
1	Road segment	139	1124	318	13312	95.8
2	Y junction	22	-	-	-	0.1
3	T junction	29	-	-	-	0.2
4	Roundabout	10	27	1	466	3.2
5	+ Junctions	5	-	-	81	0.6
6	X junction	4	-	-	-	0
7	Rail crossing	0	-	-	-	0
9	Unknown	10	-	-	-	0.1
Total		219	1151	319	13859	100

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.9 Crash by Vehicle Type

The Sub-city's Traffic Police Officer divided vehicles in to different vehicle types; bicycle, motor-bicycle, automobile, station wagon, pick up ≤ 10 quintal, truck 11-40 quintal, truck 41-100 quintal, truck with trailer, liquid cargo, taxi, minibus up to 12 seats, bus 13 to 45 seats, bus > 46 seats, earthmoving, earth moving with trailer, cart, train and others involved in the crash frequency.

Accordingly, most frequent road traffic crashes were caused by pick-up ≤ 10 quintal, automobile, taxi, station wagon(4WD), Vans(Minibus up 12 seats), and with percentage of crashes ; 25.7%, 21.8%, 20.3%, 18.1%, 4.2% respectively that constitute about 90% of the vehicles involved in road crashes. The remaining 10% of the crashes were due to bicycle (0.2%), motor-bicycle (0.7%), bus > 13 seats (1.4%), trucks(5.4%), cart and earthmoving(0.2%) and unspecified or other types (2%) of vehicle. Earthmoving with trailer, liquid cargo and train are insignificantly contributes to crash occurrence. Road traffic crash occurrence due to vehicle types for duration of three years in Bole Sub-city as shown in Table 4.6 below.

Table 4.6: Proportions of Road Traffic Crashes by Vehicles Type

No.	Type of vehicles	Fatal	Serious injury	Slight injury	PDO	Total	(%)	
1	Bicycle	1	3	1	29	34	0.2	0.9%
2	Motor bicycle	6	28	1	58	103	0.7	
3	Automobile	47	144	45	3147	3383	21.8	40%
4	Station wagon	7	171	70	2570	2818	18.1	
5	Pick up ≤10	21	277	78	3616	3992	25.7	31.1% Commercial Vehicle (Trucks)
6	Truck 11 - 40 quintal	16	44	15	348	433	2.8	
7	Truck 41 - 100 quintal	21	17	12	303	353	2.3	
8	Truck with trailer	5	-	-	43	48	0.3	
9	Liquid Cargo	-	-	-	-	-	0	
10	Taxi	19	352	81	2704	3156	20.3	20.3%
11	Minibus up to 12 seats	38	33	5	572	648	4.2	5.6%
12	Bus 13 - 45 seats	10	7	1	137	155	1.0	
13	Bus > 46 seats	3	3	-	61	67	0.4	
14	Earthmoving	-	-	-	14	14	0.1	

Table 4.6: Proportions of Road Traffic Crashes by Vehicles Type, (Contd...)								
No.	Type of vehicles	Fatal	Serious injury	Slight injury	PDO	Total	(%)	
15	Earthmoving with trailer	-	-	-	1	1	0	
16	Cart	-	1	4	14	19	0.1	
17	Train	-	-	-	1	1	0	
18	Others	4	1	-	64	69	0.4	2%
19	unknown	21	70	16	147	254	1.6	
Total		219	1151	319	13750	15548	100	

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.10 Crash by Pavement Surface Conditions

Table 4.7 summarizes the surface condition where frequent traffic crash had occurred. Pavement condition is one of contributing factors to speeding of vehicles and hence, road traffic crashes. About 99.8% of road crashes happened on asphalt roads with good pavement conditions, while poor pavement conditions only contributed 0.2% to road crashes. However, gravel roads had either insignificant contributions to road crashes or all road pavements in the Sub-city were asphalts.

Table 4.7: Crash by Pavement Surface Conditions

No.	Types of Pavement	Fatal	Serious Injury	Slight Injury	PDO	Total	Percentage (%)
1	Quality Asphalt	201	1151	319	13842	15,513	99.8
2	Poor Asphalt	18	-	-	17	35	0.2
3	Gravel	-	-	-	-	-	0
Total		219	1151	319	13,859	15,548	100

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.11 Crashes by Defects of Vehicles

To investigate the level of road traffic crashes occurred by vehicle defect, some indicators presented as; brake pedal defects, steering wheel defect, tire defects, head and tail light defects, other mechanical problems, vehicles with no defect, and unspecified. From the mentioned vehicle defects, nearly all the accidents occurred by vehicles with no defects (97.3%). The remaining vehicle defects; brake pedal defects, steering wheel defect and tire defects insignificantly contributed to road traffic accidents in the Sub-city, while head and tail light defects, other mechanical problem and unknown vehicle defects contributes to road crashes about; 0.3%, 0.1% and 2.% respectively Table 4.8.

Table 4.8: Crashes by Defects of Vehicles

Vehicle defects	Total	Percentage (%)
Brake pedal defects	7	0
Steering wheel defect	1	0
Tire defects	-	0
Head and tail light defects	39	0.3
Other mechanical problem	8	0.1
With no defect	15,133	97.3
Unknown	360	2.3
Total	15,548	100

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.12 Crash by Divider Types

Table 4.9 summarizes the percentage of road crashes on different road divider types where the crashes frequently occurred. An estimated 47.4%, 46.6%, and 5.9% of the crash frequency occurred on undivided two-way, one-way and median separated roads respectively. A number of crash frequency was recorded on divided by pavement marking roads. On two way undivided roads drivers lane changing might be the case. This implies, streets in the Sub-city lacks pavement markings that regulate traffic flow to be safer.

The crashes on one-way streets are caused due to high-speed vehicular traffic that drivers not expecting the risk of conflict from opposite vehicle. However, median separated roads appropriately regulates traffic flows and head-on collision crash type is controlled for this road divider types.

Table 4.9: Crashes by Road Divider Types

Lane type	Sum	Percentage (%)	
One way	7,239	46.6	94.0%
Undivided Two way	7,365	47.4	
Median-Separated	915	5.9	
Divided by pavement Marking	29	0.2	
Total	15,548	100	

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.13 Crash by Vehicle Maneuver

Contributions to percentage of crash frequency at a time of vehicles maneuver for three years as presented in Table 4.10 below were; entering the intersections (0.1%), diverging movement (0.1%), turning to right (1.1%), turning to left (0.6%), U-turning (0%), overtaking (0.4%), straight movement (93%), outgoing from home (0.7%), moving backward (1.4%), while parking (0.1%), and unspecified (2.4%). About 93% of crash frequencies happened when culprit vehicles were moving street forward. This kind of maneuver takes place at road segments and the vehicles are expected to be at high speed.

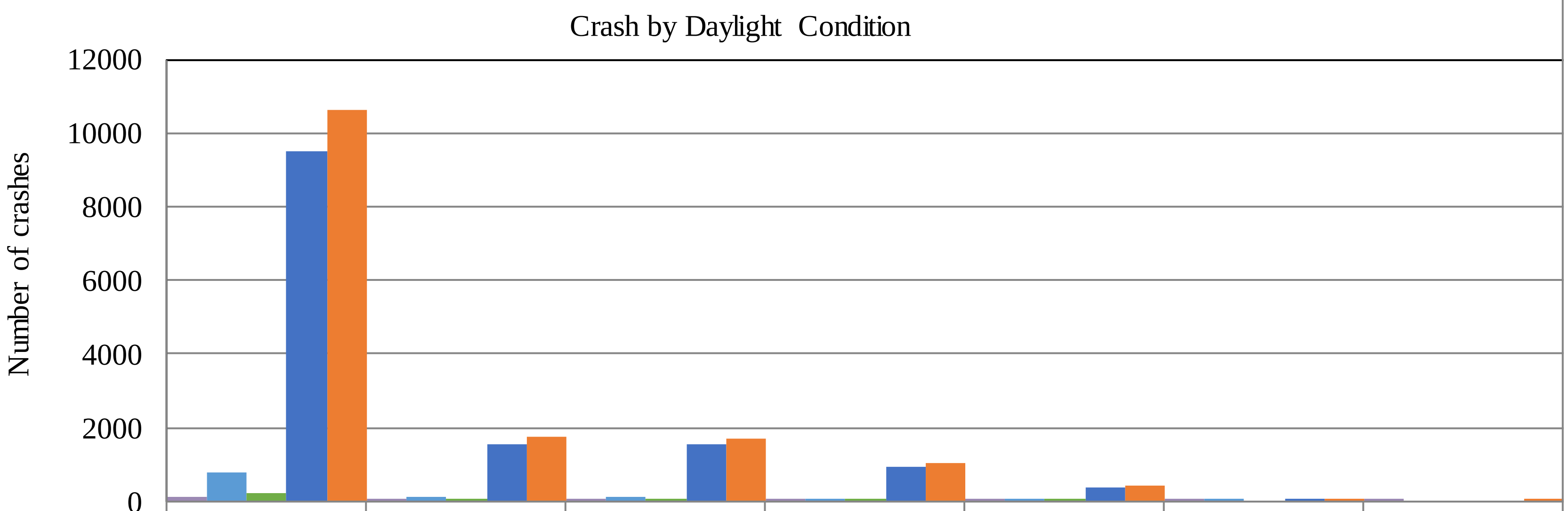
Table 4.10: Crashes by Movement of vehicles

No.	Movement of vehicles	2015/16	2016/17	2017/18	Total	Percentage
1	Entering the intersections	2	4	5	11	0.1
2	Diverging movement	3	2	4	9	0.1
3	Turning to right	30	2	136	168	1.1
4	Turning to left	18	3	77	98	0.6
5	U-turning	1	-	3	4	0
6	Overtaking	21	21	13	55	0.4
7	Straight Movement	4172	5024	5271	14,467	93
8	Outgoing from Home	40	68	4	112	0.7
9	Moving backward	86	131	2	219	1.4
11	While parking(stopping)	-	7	3	10	0.1
12	Other	5	-	2	7	0
13	Unknown	73	129	165	367	2.4
Total		4,458	5,404	5,686	15,548	100

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.14 Crashes by Light Conditions

Figure 4.6 summarizes crash happened by different light Conditions for durations of three years. Accordingly, light conditions shared different total crash frequency; day light (10,621), dawn (1,736), dusk (1,707), lighted dark road (1,028), weak lighted dark road (415), unlighted dark road (27), and unclassified (14). Even though the existence of light is very important for the reduction of road crashes, the analysis shows that most road traffic crashes occurred during the day light. Moreover, compared to day light, medium accidents were reported at dawn, dusk, lighted dark road in the Sub-city. Accidents those happened in weak lighted dark road and unlighted dark road were relatively low.



	Day light	Dawn(light before Sunrise)	Dusk(light before sunset)	Lighted dark road	weak lighted dark road	Unlighted dark road	Unclassified
Fatal	139	16	18	20	7	5	14
Seriuos Injury	787	137	122	74	28	3	0
Slight Injury	192	61	37	22	7	0	0
Property damage	9503	1522	1530	912	373	19	0
total	10,621	1,736	1,707	1,028	415	27	14

Figure 4.6: Road Traffic Crashes by Light Conditions

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.15 Crashes by Weather Conditions

Percentages of crash frequency occurred under different weather conditions and are depicted in Table 4.11 below. The analysis shows that about 87% of total crashes occurred at the time of good weather conditions whereas, only 13% of accident happened during moist-weather condition. Hence, the analysis confirms that the majority of traffic crashes happened under dry road surface conditions in the Sub-city.

Table 4.11: Crashes by Weather Conditions

Weather conditions	Sum	Percentage (%)
Dry (Good weather)	13,507	87
Moist-weather	2,041	13
Total	15,548	100

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.2.16 Crashes by Land Uses

Land uses of the Sub-city are divided into Sub-urban, school area, industry area, church area, market area, recreation area, hospital area, office area, residential area, and unspecified land uses in order to examine the accident extents in each area. Their associated percentage of crash occurrences during three years are depicted in Table 4.12 below. Accordingly, as the data collected confirmed, land uses like Sub-urbans have no accident reports during the three selected years. However, market area, recreation area, and residential area road crash most frequently occurred.

Table 4.12: Crashes by Land Uses

Land Uses	Total	Percentage (%)
Sub-urban	74	0
School area	737	5
Industry area	432	3
Church area	1,510	10
Market area	4,789	31
Recreation area	3,013	19
Hospital area	980	6
Office area	1,032	7
Residential area	2,434	16
Unknown	547	4
Total	15,548	100

Source: BTPO and AAPC (2015/16-2017/18) Computed by the Author, 2018

4.3 Road Traffic Crashes Prediction Models

There are five basic assumptions that are required to be followed while applying Poisson and Negative Binomial Regression analysis technique to give a valid and meaningful result. However, it is essential that it is not uncommon for data to be violated (i.e., fail to meet) one or more of these assumptions. Nevertheless, even when data does fail some of these assumptions, there is often a solution to overcome this.

These five assumptions are:

Assumption #1: The dependent variable consists of count data. Count data is different from data measured in other well-known types of regression (e.g. linear regression and multiple regression require dependent variables that are measured on a "continuous" scale. Binomial logistic regression requires a dependent variable measured on a "dichotomous" scale, ordinal regression requires a dependent variable measured on an "ordinal" scale, and multinomial logistic regression requires a dependent variable measured on a "nominal" scale).

In contrast, count variables require integer data that must be zero or greater. Also, since count data must be "positive" (i.e., consist of "non-negative" integer values). Furthermore, it is sometimes suggested that Poisson regression is performed only when the mean count is a small value (e.g., less than 10). Where there are large numbers of counts, a different type of regression might be more appropriate (e.g., multiple regression, gamma regression, Hence, road traffic crash (count variable without negative integers) is the modeling main dependent variable that perfectly fulfills the assumption requirement.

Assumption #2: The independent variables may be one or more, which can be measured on a continuous, ordinal or nominal/dichotomous scale. Ordinal and nominal/dichotomous variables can be broadly classified as categorical variables. Hence, in this modeling process, the explanatory (independent) variables consist of categorical (median type); painted and raised median. Moreover, continuous variables of road geometric characteristics; road length, number of horizontal curves, number of vertical curves, gradient, number of lanes, surface width, median height, median width and sidewalk width, number of access, and the exposure variable average daily traffic (ADT) are used for the road crash occurrence prediction.

Assumption #3: The observations should be independent of one another. This means that each observation is independent of the other observation; that is, one observation cannot provide any information on another observation. This is a very important assumption. A lack of independent observation is mostly a study design issue. One method of testing for the possibility of independence of observations is to compare standard model-based errors to robust errors to determine if there are large differences.

Assumption #4: The distributions of counts (conditional on the model) follow a Poisson distribution. One consequence of this is that the observed and expected counts should be equal (in reality, just very similar). Essentially, this is saying that the model predicts the observed counts well. This can be tested in a number of ways, but one method is to calculate the expected counts and plot these with the observed counts to see if they are similar.

Assumption #5: The mean and variance of the model (dependent variable) are identical. This is a consequence of assumption number four; that there is a Poisson distribution. For a Poisson distribution, the variance has the same value as the mean. If it satisfies this assumption, it has equidispersion. However, often this is not the case and the data is either under-dispersed or over-dispersed with over-dispersion the more common problem. There are a variety of methods that could be used to assess over dispersion. Negative Binomial regression technique is chosen parallel to Poisson regression for the modeling purpose in the study (Lund Research Ltd, 2015).

4.3.1 Description of Data

To establish the relationship between road geometric characteristics and occurrence of traffic crashes, data were collected from 22 road segments in Bole Sub-city. Fatal crash data were collected from the Addis Ababa Police Commission and records of injury crashes and property damage only (PDO) were collected from Bole Sub-city Police Station. After excluding records with missing variables, the data for this study included a total of 5,825 road crashes (121 fatal, 740 injuries and 4,964 PDO) which occurred on selected road segments over a period of three years (July 2015 to June 2018). Total percentage of road traffic crashes by crash severity types, descriptive statistics of categorical variables and continues variables are shown in Figure 4.7, Table 4.13 and 4.14 respectively.

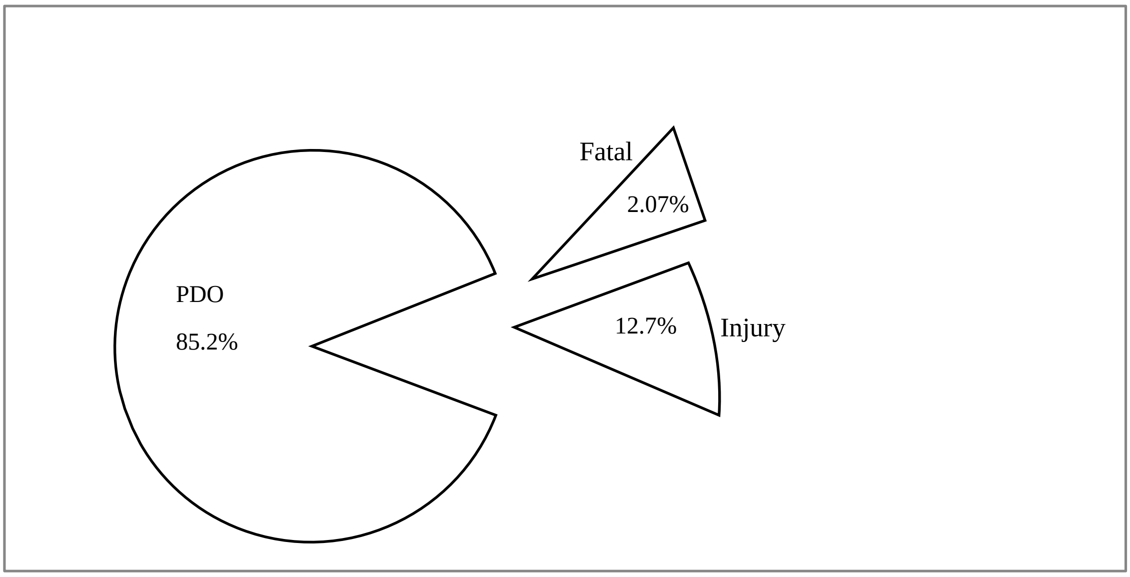


Figure 4.7: Percentage of Road Crash Severity in the Model

The explanatory variables included in the model are road geometric characteristics and exposure variables. The major road geometric design elements included in the study were:

- Number of horizontal curves;
- Number of vertical curves;
- Number of vertical gradients;
- Road segment lengths;
- Number of lanes;
- Surface width;
- Median width;
- Median height;
- Median type;
- Sidewalk width;
- Number of access points;
- Access controls; and
- Average daily traffic (ADT)

Table 4.13: Descriptive Statistics of Categorical Variables

Crash Severity		Fatal	Injury	PDO	Total	Percentage
Drivers characteristics						
Gender	Female	5	19	83	107	1.98
	Male	116	682	4512	5310	98.02
	Total	116	682	4512	5310	98.02
Driver education	College and above	30	213	1480	1723	31.81
	High school	65	357	2284	2706	49.95
	Primary and below	26	131	831	988	18.24
	Total	121	701	4595	5417	100
Driver experience	0- 5 years	72	362	2023	2457	45.36
	6- 10 years	29	134	1122	1285	23.72
	>10 years	20	205	1450	1675	30.92
	Total	121	701	4595	5417	100
Drivers' relation to vehicle	Employee	101	504	2986	3591	66.29
	Owner and Family	20	197	1609	1826	33.71
	Total	121	701	4595	5417	100
Vehicle characteristics						
Vehicle type	Auto and 4WD	55	405	2709	3169	58.5
	Minibus & Bus	46	216	1462	1724	31.8
	Truck	19	74	399	492	9.1
	Non-motorized	1	6	25	32	0.6
	Total	121	701	4595	5417	100
Roadway characteristics						
Type of median	Painted median	24	171	1341	1536	26.37
	Raised median	97	569	3623	4289	73.63
	Total	121	701	4595	5417	100.00
Road Condition						
Road condition	Dry	119	650	4450	5219	96.34
	Wet	2	51	145	198	3.66
	Total	121	701	4595	5417	100
Time						
Time of Day	Day light	58	491	3720	4269	78.81
	Night time	63	210	875	1148	21.19
	Total	121	701	4595	5417	100.00
Days						
Day of the week	Monday - Friday	88	491	3446	4025	74.3
	Weekend	33	210	1149	1392	25.7
	Total	121	701	4595	5417	100

Descriptive statistics of continues variables are different from the categorical variables in a way that they can be shown in numbers. Road characteristics and crash occurrences are categorized under this type of statistics as shown in Table 4.13 below.

Table 4.14: Descriptive Statistics of Continues Variables

Variables	Minimum	Maximum	Mean	Std. Deviation
Total crash occurrence	139	467	264.8	86.325
Road segment length in (m)	270	2870	1335	595.56
Number of horizontal curves	0	3	1.14	0.774
Number of vertical curves	0	5	1.41	1.221
Vertical grades count	0	5	1.5	1.504
Number of lanes	4	8	5.1	1.2
Surface width in (m)	9	23	15.95	3.92
Median height in (m)	0	1.3	0.27	0.33
Median width in (m)	0.15	35	5.68	10.74
Sidewalk width in (m)	1.5	5.0	3.46	1.12
Number of access	4	26	10.77	6.3
Number of Access control	0	4	0.77	1.27
Exposure Variables				
ADT	8881	41662	18791	6834
Number of Observation	22			

4.3.2 Model Selection

4.3.2.1 Crash Count Modeling Techniques

Researchers have developed a number of statistical analytical tools for analyzing crash data in the past. For example, crash count modeling techniques are used in the highway safety analysis. Lao et al. (2011) stated that different types of explanatory variables can affect road crash frequency such as road geometric, driver behaviors, vehicle, and environment. The researches indicated that both behavioral factors related to the driver's errors, and non-behavioral factors related to road geometry, vehicle, and environment can significantly affect road traffic crashes.

Lord and Mannering (2010) stated that crash frequency can be estimated in two different ways. The first crash frequency estimation techniques are conventional univariate regression models, which encompasses the Poisson Regression model, Negative Binomial model, Poisson lognormal model, zero-inflated model, and Conway Maxwell Poisson model. The other models are generalized additive models, random, parameters models, finite mixture, Markov switching models, and hierarchical models.

Road traffic accident prediction models were at the beginning based on the simple multiple linear regression models that accepts normally distributed errors (Caliendo et al., 2007). Researchers concluded that crash occurrence is more fitted with the Poisson distribution, which was developed by an advanced modeling technique (i.e. generalized linear models) (GLM). The generalized Poisson regression models are statistical modeling techniques used to model the relationships between road geometry, site characteristics, traffic variables and the expected number of resulting crashes on roadway segments or intersections. Crash data are nonlinear, random, and non-negative (count data) which approximately follow the Poisson distribution.

Poisson regression models are generalized linear models with the logarithm as the link function, and the Poisson distribution function as the assumed probability distribution of the response. Negative binomial regression is a popular generalization of Poisson regression because it loosens the highly restrictive assumption that the variance is equal to the mean made by the Poisson model (Nelder, 1972)

Tom and Elke (2014) were used the models previously discussed on rural and urban road intersections of the form given in equation 4.1 and for this study, the author considered a model for road segment in this form.

$$E(\mu i) = \beta o Q^{\beta} e^{\sum \beta i x i} \quad (4.1)$$

$E(\mu_i)$= expected number of accidents

β_o = Intercept (Estimate)

Q = Traffic Volume (ADT)

β = effect of traffic volume on the expected number of accidents and is modelled as elasticity

β_i = parameters to be estimated and represent the effect of risk factors, *i*, on the expected number of accidents other than traffic volume

x_i = vector of values of risk factors, *i*, other than number of vehicles

The effects of risk factors that influence the probability of accidents given exposure are Modelled as an exponential function that is as e (the base of natural logarithms) raised to the sum of the product of coefficients, β_i, and values of the explanatory variables, x_i, denoting risk factors.

Researchers empirically demonstrated the Poisson regression and negative binomial regression to model accident frequencies. (Miaou, 1994) for example, evaluated crashes and road features using Poisson and negative binomial model.

In recent times, investigators have proposed the possibility of using Poisson-lognormal model instead of the negative binomial to model road crash data. Moreover, the Poisson-lognormal provide more flexibility than the negative binomial.

Consul and Famoye (1992) and Famoye (1993) the probability function for the generalized Poisson regression model; f (y_i; μ_i, φ) is given by

$$f(y_i;\mu_i,\varphi) = \left(\frac{\mu_i}{1+\varphi\mu_i}\right)^{yi} \frac{(1+\varphi yi)^{yi-1}}{yi} \; exp\left[\frac{\mu i\,(1+\varphi yi)}{1+\varphi\mu i}\right], y_i = 0, 1, 2, 3, \ldots \quad (4.2)$$

Where;

$$\mu_i = \mu_i(x_i) = \exp(\textstyle\sum_{i=0}^{k} xi\beta j)\;, xi = (xi1 = 1, xi2, \ldots, xik) \quad (4.3)$$

Is the i-th row of covariance matrix X and β = β1, β2..., βk are unknown k-dimensional column vector of parameters. The model in equation 4.1 is based upon the generalized Poisson distribution and the mean of yi is given by μ_i and the variance of yi is given by μi (1+φμi) [2]. Moreover, it is an extension of the Poisson regression model. When φ = 0, the generalized Poisson distribution model reduces to the Poisson regression model. When φ > 0, the GPR model is used to model count data that exhibits overdispersion and when φ < 0, the model is used to describe count data that shows underdispersion.

Lawless (1987) and Cameron and Trivedi (1998) the probability function for the negative binomial regression (NBR) model, is given as g (y_i; μ_i, τ)

$$g(y_i;\, \mu_i, \tau) = \binom{y_i + \tau^{-1} - 1}{y_i} \left(\frac{1}{1+\tau\mu i}\right)^{1/\tau} \left(\frac{\tau\mu i}{1+\tau\mu i}\right)^{yi}, yi = 0, 1, 2, 3, \ldots \quad (4.4)$$

Where μ_i is defined in equation 4.2 that the mean of y_i is given by μ_i and the variance of y_i is given by μi (1+ τμi) [2]. The model in equation 4.3 reduces to the Poisson regression model when τ → 0. It can be used to model count data with over dispersion when τ > 0.

4.3.3 Discussion of the Result

Some of the predictor variables were found statistically insignificant in the analysis of the model. Explanatory variables such as; road segment length, vertical grade count, median height and median width were systematically removed from the model and then, interpretation for those statistically significant variables was done.

The final model is done based on the statistical significance of each predictor (explanatory) variables had with the dependent variable. Log-linear Poisson regression and Negative binomial regression model was used to investigate the effect of road geometric design elements on the road crash occurrences.

As clearly shown in the Table 4.15 the explanatory variables such as median type, number of horizontal curves, number of vertical curves, sidewalk width, number of lanes, average daily traffic, number of access points and number of access control had significant effects on the occurrence of road traffic crashes. Those explanatory variables have played significant influence for the happening of daily life taking road traffic crashes in the study area.

Table 4.15: Modeling Results

Description	Poisson Regression Model					Negative Binomial Regression Model				
	Estimated Coefficient	Standard error	95% confidence interval		P-value	Estimated Coefficien	Standard error	95% confidence interval		P- value
Constant	3.469	0.5703	2.351	4.586	0	4.25	10.033	-15.414	23.915	0.056
Road characteristics										
Painted medians	0.113	0.0430	0.029	0.197	0.008	0.107	0.7547	-1.372	1.586	0.04
Number of horizontal curves	0.094	0.0214	0.052	0.136	0	0.103	0.3687	-0.620	0.826	0.09
Number of vertical curves	0.054	0.0126	0.029	0.079	0	0.046	0.1974	-0.341	0.432	0.096
Number of lanes	0.029	0.0137	0.002	0.056	0.037	0.036	0.2242	-0.404	0.475	0.087
Side walk width	-0.059	0.0153	-0.089	-0.029	0	-0.047	0.2296	-0.497	0.403	0.084
Number of access	0.034	0.0026	0.029	0.039	0	0.035	0.0449	-0.053	0.124	0.043
Number of access controls	-0.045	0.0138	-0.072	-0.018	0.001	-0.045	0.201	-0.457	0.366	0.083
Exposure Variable										
LOG ADT	0.375	0.1461	0.089	0.661	0.010	0.170	2.5676	-4.862	5.203	0.095
Dispersion parameter						0.69				
Log-likelihood value at Convergence	-178					-144				
Log-likelihood value at Zero	-220					-179				
AIC/N =	17.05					14.00				
Number of observation	22									

When road segment with raised median is compared with painted median, painted median positively affects crash occurrences. The result shows higher road crashes occurred at road segments with painted median since the raised medians partially (or fully) controls the vehicle's movement from one direction to others, while painted medians allow vehicles maneuvers at any locations of the road segments. In addition, the painted median types of the study location were two directional lane with poor channelization of opposite direction vehicles movements that is exposed to road crashes. The study conducted in Las Vegas Valley inferred the road segments with raised median had lower rear-end, sideswipe and injury crash rates by 18.7%, 21.7%, and 23.7%, respectively (Timur, 2010).

The number of horizontal curve variable has a positive coefficient. This explains that when the number of horizontal curves in a given road segment increases, road traffic crash frequency also increases which affect road safety. The finding is consistent with study conducted in Addis Ababa, which found that the more number of horizontal curves in a road segment increase traffic crash and cause a safety problem for lack of concentration by drivers and high-speed vehicles. Limiting the number of horizontal curves during design of new road and controlling already built road is an important safety criteria (Tefera, 2015)

Vertical curve variable has a positive coefficient, which indicates that an occurrence of road crashes in a specified road section are positively associated with the number of vertical curve in the road segments. This indicates, more number of vertical curve on road sections results in road crash frequency. A study was conducted on effect of vertical alignment on driver perception of horizontal curves and found that perception of the driver of the road features ahead is an important human factor and should be addressed during road design.

An erroneous perception of the road can lead to actions that may compromise traffic safety. Poor coordination of horizontal and vertical alignments is believed to cause such wrong perceptions (Mohita, 2014). The overtaking maneuver, movements to driveways or access on the vertical curves, there is increased potential for crash risk, particularly when sight distance is short and drivers are not concerned.

The number of lanes has a positive correlation in the coefficient of estimated model, which implies that the more the number of lanes, the higher road traffic crashes at road segments. A study conducted in Addis Ababa supports this findings that vehicles on mid-block segments with more lanes run at higher speed and more traffic flow leading to more crashes and also, vehicles travel along the midblock segment with more number of lanes have more lane changing and overtaking opportunities (Alemu, 2016). The study conducted in Florida also concluded that wide pavement surface and multiple lanes had significant weaving maneuvers on major approaches, tends to increase the risk of crash frequency (Zhenyu et al., 2011)

The coefficient for a number of access control variable is negative, which implies that less crashes occur on a road segment with more access control in it. This result makes sense because more access control creates less opportunity for conflicts, and thus tend to cause less crashes. Access control techniques are used to improve traffic performance and safety on highways. One important benefit of access control is improved safety (Henry and Andrzej , 1999).

Sidewalk width is another a significant explanatory variable to crash occurrence with a negative estimated coefficient. The finding implies road crash frequency decreases as the width of the sidewalk increases.

A study conducted in Addis Ababa support the findings that it explained the city uses walking as the primary means of transportation accounting for about 60% of the total trips within the city. The lack of separation between vulnerable road users and motorized traffic leads to a considerably larger set of potential crash risk opportunities for pedestrians compared to separated facilities encountered in developed countries. Consequently, as the width of sidewalk decreases, the pedestrians are forced to use roadways with motorized traffics (Tulu et al., 2013).

The coefficient for number of access variable has positive relationship with road traffic crash occurrence on the road segments in the model. This is due to insufficient sight distance provision for minor intersections. Consequently, it causes road traffic collision between vehicles coming from access road and the road segment. Moreover, road segments associated with high number of access exposed to unexpected traffics that collide with high-speed vehicle on the road segment. Provision of access controls and different traffic control devices, it is possible to reduce road traffic crashes (Tefera, 2015).

Exposure variables, a logarithm of the average daily traffic (ADT) has positive coefficient, which indicates that when there is more traffic volume in a road segment, more traffic crashes occur. Alemu (2016) stated that due to more interactions between vehicles, many potential conflicts in mid-block road segment can cause more crashes. The vehicles entering the road from the driveway had no gap to join the road and so, the driver was forced to enter the road illegally.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

The study has developed crash prediction statistical models on the effect of road geometric design parameters on road traffic crash occurrences using crash counting model (Poisson log-linear regression and negative binomial regression) model based on three years crash records from July 2015 to June 2018. Moreover, descriptive general analysis of crash trends in Bole Sub-city is incorporated in the study.

Selected road geometric parameters in the study were: number of horizontal curves, number of vertical curves, vertical gradient counts, length of road segments, number of lanes, surface width, sidewalk width, median type, median height, median width, number of road access and number of road access controls. In addition, average daily traffic (ADT) was also included in the model as an exposure variable. The study used twenty-two representative road segments to achieve the stated objectives using convenience sampling method from Bole Sub-city based on the requirements to obtain a sample of road segments incorporating a different road geometric design elements. Among these mid-blocks, 17 were found to be raised medians and the rest five were painted medians. To estimate ADT, peak hour count method was used and the other road geometric parameters were measured from the study sites.

The model shows that road traffic crash frequency in selected road segments in the Sub-city is influenced by average daily traffic as an exposure variable, number of horizontal curves, number of vertical curves, number of lanes, surface width, sidewalk width, median type, number of road access and number of access control.

However, length of road segments, number of vertical grade, median width and median height were found statistically insignificant in the output of the model.

Similarly, painted medians had positive correlation with road crashes. Further, road segments with painted medians had higher road traffic crashes compared with raised median. Moreover, number of horizontal curves, number of vertical curves, number of lanes, number of access (or driveways) and average daily traffic positively affected road traffic crashes that occurred on the selected segments. The result implies that as the numbers of these explanatory variables increases in the road segments, the corresponding crash occurrences also increases. On the other hand, sidewalk width and number of road access controls had negative coefficient. This indicates that as width of sidewalks increase and also the number of access controls on the road sections, the chance for potential crash risk is reduced.

The study found that general crash analysis in the Bole Sub-city reveals that most crashes occurred at road segments, undivided two-way and one-way roads, particularly in market and recreation areas. In addition, it revealed that road crash frequently occurs on a tangent road with flat terrain road geometry, quality asphalt, and rear-end collision types.

5.2 Recommendations and Future Research

5.2.1 Recommendations

Based on the collected data and the analysis, as well as from the perspectives of the main causes of road crashes, the following recommendations were given to facilitate road safety at the road segments.

- The Addis Ababa Road Traffic Management Agency should expend considerable resources and effective monitoring in an effort to improve safety by implementing countermeasures that include improving highway geometrics, highway signing, and other road safety considerations.
- High raised pedestrian crossing structures should be provided specially in front of markets, schools and church areas considering disabled persons.
- Changing painted medians to raised medians is recommended since they were more effective on road safety than the painted median.
- Minimizing road access (or driveways), placing warning signs at the roads access, and also removing obstacles from road layouts.
- Providing well-constructed sidewalk on the both sides of road segments for pedestrians.
- Provide access control (or fences) to guide both vehicles and the pedestrians.
- Providing properly channelized traffics.
- Banning street shops (or not to sell) some goods on the sidewalks of road segments.
- Trimming trees from the road medians that limits the visibility of the driver during the turning maneuvers.
- Providing Posted speeds on each directions of road segments and taking measures on the drivers that breaks speed limits.

- The transport authority should consider proportionating a number of lanes with average daily traffics as safety criteria, and as well as number of horizontal and vertical curves, sidewalks and driveways while designing the new street and the rehabilitations of the existing road geometric design elements.
- Providing appropriate crash location information.

5.2.2 Future Research

- The study tried to address the influence of road geometric design elements on road traffic crash frequency in Bole Sub-city. As the result shows, road geometric parameters had a significant role on the crash occurrences at road segments resulting in both loss of human lives and properties. On the other hand, the incorporation of other important road geometric parameters and its environments like; posted speeds, sight distances, land uses, and road traffic management related issues with more sample sizes and data are recommended to be from different sub cities. Accordingly, further research is required in this area.

- Moreover, pedestrian volume from exposure variables is recommended to be included in the model for more realistic findings in the future studies. Furthermore, it’s shown in the general causes of accidents analysis that human error contributes about 93.5% to road traffic crashes. Therefore, human factor (or drivers' attitudes and behaviors) need to be considered as explanatory variables on the road crashes to further research.

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APPENDICES

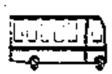
Data Collection Formats

Appendix A: Road Geometry Data Format

#	Road segment		Road Geometry				Other control points		
	start	End							
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									

Appendix B: Peak hour Traffic Volume Counted Data Format for Motorized Vehicles

Road Segment Name: ___________________________ Starting Point: ________________ End Point: _________________

Time	Vehicles Classifications							
	V1 (Car)	V2 (4-wheel drive/4WD)	V3 (Mini bus)	V4 (Large Bus)	V5 (Small Truck)	V6 (Medium Truck)	V7 (Heavy Truck)	V8 (Articulated Truck)
Starting time End time respectively								
1:30 1:45								
1:45 2:00								
2:00 2:15								
2:15 2:30								
Total								

Appendix C: Traffic Volume Counted Data Format for Motorized Vehicles on Days of Week

Road segment________________________ Start____________________________ End ________________________________									
Day	Car	4WD/Station Wagon	Small Bus	Large Bus	Small Truck	Medium Truck	Heavy Truck	Articulated Truck	Date
Sunday									
Monday									
Tuesday									
Wednesday									
Thursday									
Friday									
Saturday									
Total									

Appendix D: Traffic Crashes Data Collecting Format

Sub-city: ____________________________ Year___________________________________

Number	Month	Day of week	Time	Driver				Vehicles service of year	Type of vehicle	Relation with vehicle	Defect of vehicle	Road geometry	Types of Pavement surface	Road condition	Weather condition	Illumination cond.	Direction of travel	Type of Crashes	Severity				Road User Information				Crash location	cause of crashes
				sex	Age	Experience	Edu. Back ground												Death	Heavy crashes	Light crashes	PDO	Number	Sex	Age	Job		

BIOGRAPHY

Alemayehu Feyissa Gerba was born in November 1989 in Ethiopia, Oromia Regional State Gida Ayana District. He graduated from Haramaya University in 2013 in B.Sc. Degree in Civil and Urban Engineering field. In addition, he graduated from Addis Ababa Science and Technology University (AASTU) in February 2019 in M.Sc. Degree in Civil Engineering specialization in Road and Transport Engineering. Currently, he has been working at Addis Ababa Science and Technology University on position of Lecturer. In addition, he has worked on position of Head department of Civil Engineering. Moreover, he has two years industry experience at Addis Ababa Science and Technology University project office on part time basis on road infrastructure project. He has participated and successfully completed the training prepared by Addis Ababa Traffic Management Agency on Vissim and Vistro Traffic analysis software, and on road safety audit and urban road design. In addition, he has skill and knowledge of road design software's like Inroad, MX road, SPSS, Eagle point, and AutoCAD.